Fire and Life Safety Analysis of

The Production Facility (PF) - 870

Sandia National Laboratories, Albuquerque, New Mexico USA

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FPE596 – Culminating Final Project Report

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Key words: Fire and Life Safety Analysis, Life Safety Code, RSET, ASET, Performance Based Design, Fire Dynamics Simulator (FDS).

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1. Executive Summary

The purpose of the fire and life-safety analysis was to perform a prescriptive-based and performance based analysis on the fire and life safety systems in the Production Facility (PF) at Sandia National Laboratories (SNL). The prescriptive-based analysis determined if the building met applicable code requirements for existing life safety systems. The performance-based analysis consisted of a series of fire scenarios to ensure the fire and life safety systems allowed adequate egress time for occupants in the event of a fire.

The prescriptive-based analysis was based on the Life Safety Code (LSC) and the International Building Code (IBC). The occupancy of each area was classified according to the use of the area and the hazards that exist. The applicable codes were used to determine if the life safety systems were appropriate for each occupancy classification. Life safety systems include: egress, fire suppression, fire alarm, and structural fire protection. The capacity of the egress system was calculated and compared to the occupant load. Analysis of the fire suppression system determined if the automatic sprinkler system was designed and installed to National Fire Protection Associate (NFPA) standards. The sprinkler water demand was calculated to ensure the water supply for the building was adequate. The fire alarm system was analyzed for proper spacing of detection and notification appliances. The electrical demand of the alarm system was calculated to ensure the battery backup supply was sufficient. The structural fire protection analysis confirmed proper materials and separation requirements existed in the building.

The performance-based analysis used stakeholders' goals and objectives to select appropriate fire scenarios to test the abilities of the installed fire protection systems. The first fire scenario was a kitchenette fire open to the main corridor with ineffective sprinklers. The second scenario was a kitchenette fire with the sprinklers active. The Society of Fire Protection Engineers (SFPE) hydraulic model, DETACT, and Pathfinder were used to calculate the required safe egress time (RSET). Fire Dynamics Simulator (FDS) was used to calculate the available safe egress time (ASET). A fire scenario was considered successful if the ASET was greater than the RSET.

For the first scenario mentioned above (kitchenette fire-no sprinklers), the fire starts with the ignition of a microwave oven that subsequently causes a wood table and adjacent coffee maker to ignite and burn. During fire modeling simulations, it was found that after 66 seconds (ASET) the occupants would have to travel through a layer of smoke and hot gas in order to exit the building. Visibility was the most limiting condition, therefore the life safety criteria for this scenario was not met.

For the second scenario (kitchenette fire with sprinklers), the fire starts exactly like the first scenario, except this time sprinklers activate and suppress the fire. During fire modeling stimulations, it was found that after 128 seconds (ASET) the occupants would have to travel through a layer of smoke and hot gas in order to get to the south exit. The exits are clear at 176 seconds (RSET). Due to the smoke layer height being at an acceptable level, this scenario was considered successful.

Recommendations for the aforementioned fire scenarios would be to keep exits clear, ensure sprinklers are operational, limit the amount of secondary combustibles in the kitchenette area, and replace suspect or malfunctioning appliances.

2. Building Overview

The Production Facility (PF) is an existing structure located at Sandia National Laboratories (SNL) in Albuquerque, New Mexico (SNL/NM). National Technology and Engineering Solutions (NTESS) operates SNL for the U.S. Department of Energy (DOE) and all the buildings at SNL are designed to adhere to strict DOE Order requirements in addition to complying with nationally adopted codes and standards. Figure 1 shows front and back satellite views of the facility.

Figure 1 – Satellite Views of the Production Facility

This facility has three distinct wings (North, West, and East). The North Wing is two stories in height with a basement, while the East and West Wings are one story each and they do not have basements. The PF was originally constructed in 1959, however in 1995, two (North and West Wings) of the three wings were razed and rebuilt; the East Wing of the facility was left standing, however it was completely gutted and remodeled. Figure 2 shows building interior space types of the three levels of the PF-Building 870 (from left to right, is the Basement, 1st floor, and 2nd floor). Refer to Appendix A for Location Maps that depict the physical location of the PF at SNL.

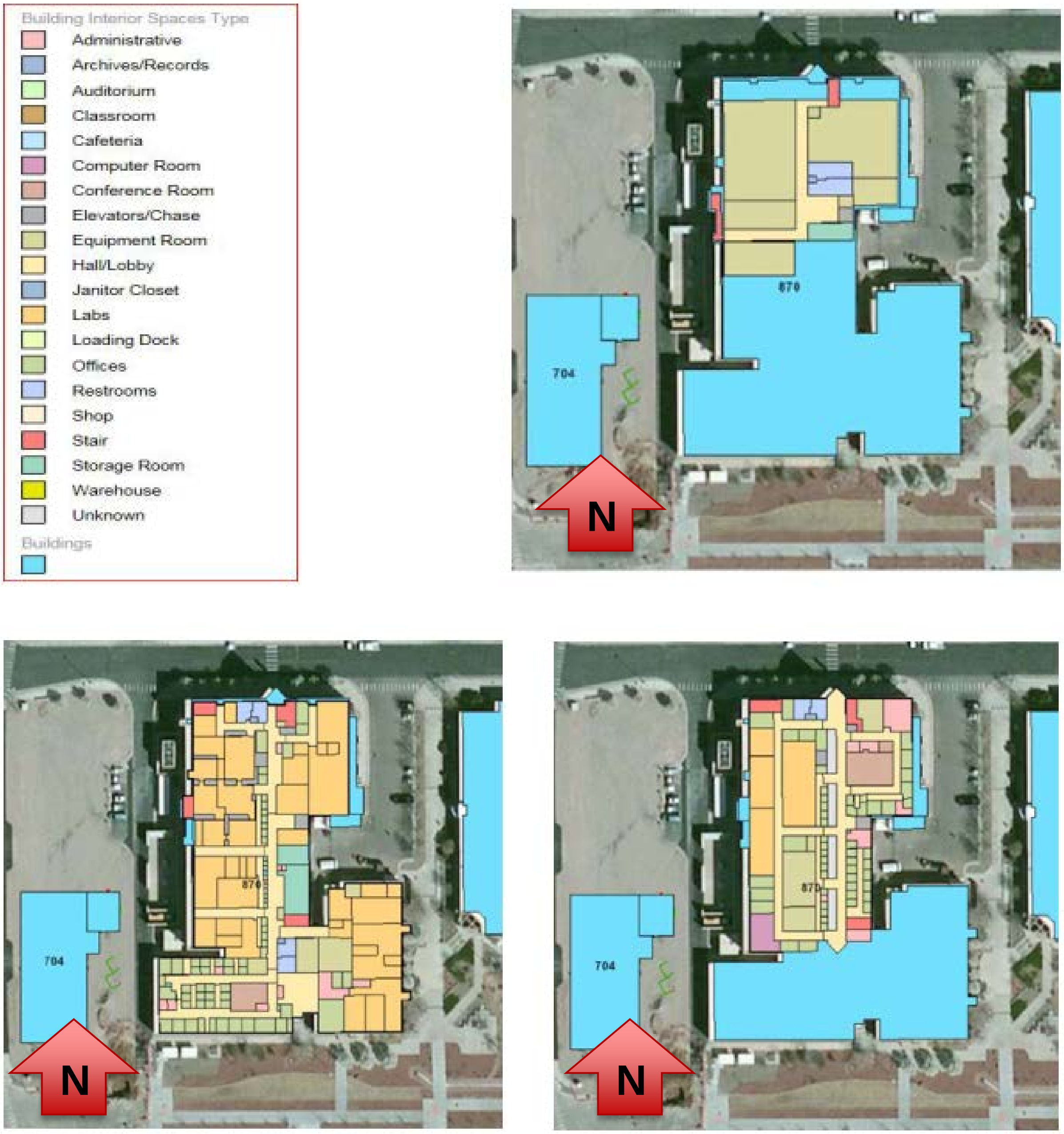

Figure 2 – Building Interior Space Types for the Three Levels of the PF

This structure's building construction consists of a concrete slab-on-grade foundation; gypsum board on metal studs cementicious stucco covered exterior walls, and a non-protected steel frame superstructure. The roof assembly is an insulated metal deck supported by unprotected steel beams and trusses.

The design of the building itself has been arranged to provide a two-hour cut-off barrier between each of the wings as a means of reducing potential common mode failures as directed by the user group. This arrangement, along with further interior subdivisions with one-hour rated fire walls for processes in the North and East Wings and automatic sprinkler protection throughout, make the probability of a total conflagration fire event extremely low.

In addition to the automatic wet-pipe sprinkler system, the building is provided with a wet standpipe system and an addressable fire alarm system. Lastly, there are a compliant number of fire hydrants located near the facility.

3. Applicable Codes, Standards, and References

- 29 CFR Part 1910, Occupational Safety and Health Standard
- 29 CFR Part 1926, Safety & Health Regulations for Construction
- DOE Standard 1066-2012: Fire Protection Design Criteria
- DOE Order 420.1.C: Facility Safety
- Sandia National Labs Site Specific Specifications
- 2015 International Building (IBC®) and Fire Code (IFC®)
- 2013 - NFPA 13, Automatic Sprinkler Systems Handbook
- 2015 - NFPA 45, Standard on Fire Protection for Labs Using Chemicals
- 2015 - NFPA 72, National Fire Alarm and Signaling Code
- 2017 – NFPA 80A, Recommended Practice for Protection of Buildings from Exterior Fire Exposures
- 2015 - NFPA 101, Life Safety Code (LSC)
- NFPA Fire Protection Handbook (19th and 20th Editions)
- SFPE Handbook of Fire Protection Engineering (4th & 5th Editions)

4. Prescriptive-Based Analysis

4.1. Introduction to Prescriptive-Based Analysis

The following analysis is performed using the LSC and the IBC. A prescriptive-based analysis compares the building to the applicable codes and standards and provides a better understanding of where codes are met and not met within the building. The prescriptive based analysis does not account for occupant characteristics as well as proposed uses for specific rooms. This analysis typically considers the worst case scenarios in order to ensure all future uses of the building will meet the code. Sandia utilizes both the IBC and the LSC for prescriptive-based design work. Both codes will be compared to this building and the more stringent code will be applied.

4.2. Occupancy Classification - IBC

The PF contains offices, equipment rooms, mechanical/electrical rooms, meeting rooms, labs, and clean rooms. Table 1 provides the classification of the occupancies within the building based upon Chapter 3 of the 2015-IBC.

Table 1. Building Occupancies per the IBC

Description of Use	Occupancy Classification
Conference Room	Assembly (Use Group A-3)
Office	Business (Use Group B)
* Incidental Use Room/Area	Business (Use Group B)
** Lab and Clean Room	Business (Use Group B)

*Incidental use rooms/areas for this facility consist of storage and equipment rooms in accordance with Table 509 of the 2015-IBC.

**The labs and clean rooms were re-classified as Group B occupancies (per 304.1 of the 2015-IBC) rather than their original H-6 (per the 1991-UBC code-of-record) occupancy classification due to their inadequate separation with other areas (specifically at the floor/ceiling assemblies) and maximum allowable quantities (MAQ) of hazardous materials were found to be below the allowable limits stated in Section 307 of the 2015-IBC. The Group A-3 Assembly occupancy listed in Table 1 above constitutes approximately 2,790-sq ft. of the 1st floor of the PF. Since the total 1st floor area is 49,829-sq ft., the aggregate areas of the A-3 occupancies do not occupy more than 10-percent (.10 X 49,829 = 4,983-sq ft. > 2,790-sq ft.) of the story they occupy as stated in Section 508.2.1 of the 2015-IBC; they are thereby considered "accessory" to the main occupancy.

4.3. Occupancy Classification – LSC

Table 2 provides the classification of the occupancies within the building based upon Section 6.1 of the LSC:

Table 2. Building Occupancies per the LSC

Description of Use Occupancy	Occupancy Classification
Conference Room	Assembly
Office	Business
Storage	Storage
Lab and Clean Room	Business
Mechanical/Equipment Rooms	Industrial – General and high hazard

4.4. Occupant Loads

A comparison of the occupant load factors from the IBC and LSC can be found in Table 3 below. The occupant load factors were taken from LSC Table 7.3.1.2 and IBC Table 1004.1.2.

Table 3. Building Occupant Load Factors

Use	LSC Load Factor (ft2/person)	IBC Load Factor (ft2/person)
Assembly	15 net	15 net
Business	100	100
Industrial – General and high hazard	100	-
Storage	500	300
*Mechanical/Equipment Rooms	-	300

* The mechanical/equipment rooms are classified as "Industrial Use" for the LSC occupant load factor.

Based on Table 3 above, it is clear that the LSC offers more specific occupancy classifications for the PF while keeping similar load factor requirements as the IBC. Storage use is the only significant difference between the occupant load factors. Reference Appendix B for occupant loads per floor tables.

4.5. Building Occupants

The majority of the occupants at the PF are engineers, scientists, and office staff members who work in the building five days a week. High-school and college interns work in the building year-round and especially in the summer. These interns can be less familiar with the building and may be as young as sixteen. All PF occupants are able-bodied and capable of a reasonable egress times. Visitors to the building may have physical disabilities that could decrease their movement times, such as being wheelchair bound, however, there would only be a very small number of individuals requiring increased movement time.

4.6. Building Characteristics

4.6.1. Description

This PF has three distinct wings (North, West, and East). The North Wing is two stories in height with a basement, while the East and West Wings are one story each. The facility has a gross area of 96,841 sq. ft.; it is 45-feet tall at its highest peak. The roof height of the single-story East and West Wings is approximately 16-feet. The roof portion of the two-story portion of the North Wing of the building has a height of approximately 35-feet, with the peak of the Clerestory having a height of approximately 45-feet.

4.6.2. Construction Type

The allowable construction type(s) for the PF was determined by using Table 503 of the 2015-IBC. The tallest wing is 2 stories with a basement and the overall facility has a gross area of 96,841 square-feet (18,691 for the basement, 49,829 for the first floor, and 28,321-sq ft. for the second floor). The basement is located approximately 19-feet below the 1st floor grade. The overall building height of the PF is 45-feet above the level of fire department vehicle access, with the highest occupied floor being at approximately 25-foot above that level. Since the highest occupied floor level is less than 75-feet, the building is not considered a high-rise per Section 403 of the 2015-IBC.

The PF is situated on a level lot with all the sides of the building fronting on a public way or open space having 20-feet minimum width. At SNL, multiple buildings are typically located on the same lot (aka, Technical Area groupings) and therefore, the entire distance between buildings or the public way width is permitted to be used according to Section 506.2.1 of the 2015-IBC. The weighted average of the widths of the public way or open space exceed 30-feet, therefore, a value of 30-feet is used as required by Section 506.2.1 of the 2015-IBC. The frontage increase was calculated to be 75-percent as shown below:

$$I_f = \left(\frac{1445}{1445} - 0.25\right)\left(\frac{30}{30}\right) = 0.75\ OR\ 75\%$$

It's worth mentioning that Unlimited (UL) Area buildings are permitted where the minimum yard distance on all sides is 60-feet, and occupancy, sprinklers, and number of stories (max. of 2) meet the criteria in Section 507 of the 2015-IBC. A frontage increase factor of 1.5 is allowed to be used for buildings that meet the aforementioned criteria. Due to construction at an adjacent facility to the PF, not all of the public way measurements could be confirmed for this facility, therefore this frontage increase factor was not used.

Since the PF is fully sprinklered in accordance with NFPA 13, then according to 504.2 of the 2015-IBC, the values specified in Table 503 for maximum building height can be increased by 20-ft and the maximum number of stories can be increased by one (1). These increases are shown in Table 2.

The North Wing has a basement and in accordance with 506.4 of the 2015-IBC, the Exception states in part that "a single basement need not be included in the total allowable building area, provided such basement does not exceed the area permitted for a building with no more than one story above grade plane." The area of a single basement is not required to be counted as part of the total building area when evaluating total allowable area in accordance with Section 506.4.1 of the 2015-IBC.

Table 4 below shows the types of construction that would be allowed with the aforementioned automatic sprinkler and frontage increases; this table uses values from Table 503 of the 2015-IBC. The PF basement area (18,691-sq ft.) is excluded from the total allowable building area since it is less than any of the maximum area/story values calculated in Table 4. As shown, only the Type V-B construction would not be allowed since the total allowable building area in Table 4 (67,500-sq ft.) is less than the aggregate gross square footage of the 1st and 2nd floors (49,829 + 28,321 = 78,150-sq ft.) of the PF.

Table 4. Types of Construction with Area, Height, Frontage and Sprinkler Area Increases

Added Fire Protection Features	Max Height w/ Sprinklers	Max Stories w/ Sprinklers	Max Story Area w/ Sprinklers & Frontage Area	Total Allowable Bldg. Area	Acceptable
Const. Type	*Equals Max Height+2*	*Equals +1story*	*Aa={At+[At*If]+[At*Is]}*	*Aa*2*	
IA	UL	UL	UL	UL	Yes
IB	180	12	UL	UL	Yes
IIA	85	6		28125	Yes
IIB	75	4	86250	17250	Yes
IIIA	85	6	106875	21375	Yes
IIIB	75	4	71250	14250	Yes
IV	85	6	135000	27000	Yes
V-A	70	4	67500	13500	Yes
V-B	60	3	33750	6750	No

As shown in Table 4 above, the minimum construction permitted for the building is Type V-A, however, design documents show that the PF was built as a Construction Type II-B building. Record design documents show that the building was constructed as a Type II-B construction (Type II-N per 1991 UBC code-of-record). Table 5 summarizes the height and area values for a fully sprinklered Type II-B Group B occupancy

Table 5. Height and Area Calculations

Requirements/Details	Values
Floor Area	**Use Group B**
Tabular Area per Story (Table 503)	23,000 square feet
Frontage Increase (Section 506.2)	17,250 square fee
Sprinkler Increase (Section 506.3)	46,000 square feet
Maximum Allowable Floor Area	86,250 square feet
Total Allowable Building Area	172,500 square feet
Building Height	
Tabular Building Height (Table 503)	55 feet
Automatic Sprinkler System Increase (Section 504.2)	20 feet
Total Building Height Allowed	75 feet
Actual Building Height	45 feet
Number of Stories	
Tabular Building Height (Table 503)	3 stories
Automatic Sprinkler System Increase (Section 504.2)	1 stories
Total Building Height Allowed	4 stories
Actual Building Height	2 stories plus a basement

As shown in Tables 5 above, the PF is compliant with the maximum allowable building area, building height and number of stories per 2015-IBC requirements for a Type II-B construction building.

4.6.3. Building Use

The PF is used for research and light production that utilizes chemical, physics and electronic laboratories and office support areas in order to support the laboratory mission. On average, there are approximately 140 people (occupant load calculations allow up to 857 people) occupying the entire building; these occupants are trained to be familiar with their work hazards and are capable of self-preservation in the event of an emergency.

4.6.4. Occupancy Separations

The PF does not require fire-resistive protection for building elements except for those that are part of a fire barrier. The North, East and West Wings are separated by 2-hour fire-resistive construction barriers. Door opening protectives in these 2-hour walls were designed with a 90-minute fire-resistance rating which is in compliance with Table 716.5 of the 2015-IBC.

The exit stair enclosures, single elevator shaft and multiple utility shafts are constructed as one-hour fire resistive shafts as required for exit stair enclosures and shafts connecting less than four (4) stories. Door assemblies in the required 1-hour-rated shafts, exit stair enclosures and exit passageways have a fire resistance rating of 60-minutes per the code of record (i.e. – Section 3309 of the 1991 UBC) as well as the current code requirements of the 2015-IBC. Door assemblies in other 1-hour fire barriers (e.g. – control areas, electrical rooms) have a fire-resistance rating of 45 minutes which is in compliance with Table 716.5 of the 2015-IBC. Reference Appendix C which shows rated walls at the PF.

The typical fire-resistive wall construction was determined to be 5/8-inch Type “X” gypsum board on metal studs in office and light laboratory areas. These walls were provided for several reasons including NFPA 318, Section 708 of the 1991 UBC requirements for separation of mechanical rooms. The clean rooms were constructed with one-hour fire-resistive separation in accordance with the requirements in NFPA 318. Ceilings are suspended mineral tiles in the office areas. Gypsum board ceilings were provided for the humidity room and main computer rooms. All light laboratories and cleaning areas have non-shedding, noncombustible ceiling tiles.

Section 707.5 of the 2015-IBC requires fire barriers to extend from the top of the foundation to the underside of the floor or roof sheathing. Section 707.6 limits the size of an opening in the fire barrier, however the PF is fully sprinklered and that allows the openings to not be limited to 156-sq ft. per Exception 1. Openings in the fire barrier shall be protected in accordance with Section 716 and penetrations shall be protected in accordance with Section 714. Joints in the fire barrier shall comply with Section 715. Section 603 of the 2015-IBC describes combustible materials that are permitted to be used for caulking and sealing around joints, penetrations, and openings in rated assemblies.

Recent site surveys confirmed that sampled fire barriers and their associated penetrations, were installed/protected in accordance with the aforementioned 2015-IBC requirements.

4.6.5. Communicating Space

The PF building contains a 2-story communicating space (aka, Atrium by current codes) connecting the 1st and 2nd Floor levels. In accordance with the 2015-IBC, an "atrium" is defined as an opening connecting two or more stories other than enclosed stairways, elevators, hoist ways, escalators, plumbing, electrical, air-conditioning or other equipment, which is closed at the top and not defined as a mall. Section 404.5 of the 2015-IBC Exception states that smoke control is not required for atriums that connect only two stories. In accordance with Section 404.6 of the IBC (2015 Ed.) and Section 8.6.7 of NFPA 101 (2015 Ed.), atrium spaces shall be separated from adjacent spaces by a 1-hour fire barrier. Figure 3 shows an interior view of the communicating space looking up from the 1st floor level.

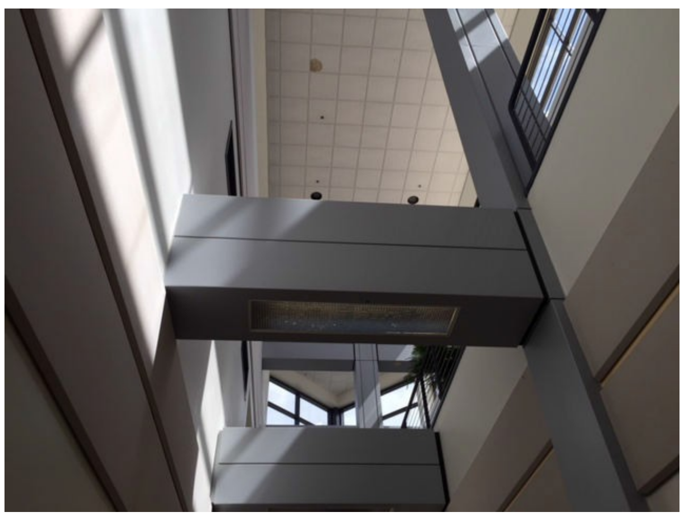

Figure 3 – Interior View of the Communicating Space

Previous editions of the building code, including the 1991 UBC (code-of-record), defined an atrium as an opening connecting *three* or more stories, therefore the building did not have to meet atrium requirements at the time of construction; this type of area was referred to as a communicating space between floors. In accordance with Section 1706 and Table 17-A of the 1991 UBC, the communicating space was designed as an area for evacuation assistance with a one-hour fire-resistance rating. Therefore, the one-hour fire resistive corridors that are part of this atrium space, as well as the continuation of these corridors to the building exits, will be maintained. This passive fire protection feature has been retained to comply with the communicating space provisions of the 1991 UBC (code-of-record) and the current atrium provisions of the 2015-IBC.

4.6.6. Fire Resistance Ratings

Table 6 below, is a summary of the required fire resistance ratings and opening protection requirements for the PF's Type II-B construction in accordance with IBC-2015 Tables 601 and 602, unless otherwise noted:

Table 6. Building Elements

Building Element	Required Fire Resistance Rating	Provided/Actual Fire Resistance Rating
Structural Frame (beams and columns)	0 Hours	0 Hours
Bearing Walls (exterior)	0 Hours	0 Hours
Bearing Walls (interior)	0 Hours	0 Hours
* Nonbearing Walls (exterior)	0 Hours	0 Hours
*Unprotected Openings (IBC Section 705.8)	Not required	Not required
Nonbearing Walls and Partitions (interior)	0 Hours	0 Hours
Floor Construction	0 Hours	0 Hours
Roof Construction	0 Hours	0 Hours

* The PF is fully sprinklered and has a fire separation distance of greater than 30-feet on all sides; therefore the exterior nonbearing walls do not require a rating in accordance with Section 705.8 and Table 705.8 of the IBC.

As previously mentioned, the North, East and West Wings of the PF are separated by 2-hour fire-resistive construction barriers. Door opening protectives in these 2-hour walls were designed with 90-minute fire resistance ratings.

4.6.7. Interior Finish

Table 7 outlines the required interior wall and ceiling finish requirements in accordance with 2015-IBC for a sprinklered Group B occupancy.

The PF record documents state that all interior finish materials are UL-listed for a flame spread index rating of 25 or less and a smoke developed index rating of less than 50.

Table 7. Wall and Ceiling Finish

Component	Minimum Required Classification	Provided Classification*	Flame Spread Index	Smoke Development Index
Exit Enclosures/Passageway	B	I	0-25	0-450
Corridors	C	II	26-75	0-450
Rooms/Enclosed Spaces	C	III	76-200	0-450

*The provided classification designations are based off Tables 42-A and 42-B of the 1991-UBC (code-of-record) for a Group B occupancy.

The floor finishes for the PF include carpet tile in the office areas, vinyl tile in corridors, and sealed concrete in light laboratories and storage areas. The PF has code compliant wall and ceiling finishes throughout.

4.6.8. Summary

The PF's occupancy and building characteristics meet all the requirements of the current codes and standards and help limit potential damages from a fire. The minimum construction type for the PF was determined to be a Type V-A, however the building was constructed as a Type II-B which is a more robust construction type. Since this building is fully sprinklered and has a fire separation distance of at least 30-ft on all sides, the exterior nonbearing walls do not require a rating. The interior finishes specified are also acceptable, however the use of rooms and areas can change and will need to be evaluated on a case-by-case basis when missions change.

An important step in developing the life safety design of a building is the design of a code compliant egress system. The next section in this report reviews and discusses the means of egress components and their design for the PF.

4.7. Means of Egress

4.7.1. Introduction

Means of egress components are required to comply with the provisions of Chapter 10 of the IBC and Chapter 7 of the LSC. The components addressed in this section include the number of exits, exit capacity calculations, arrangement of the means of egress, horizontal exits, and exit signs. Figure 4 below shows the PF main hallway on the first floor looking south.

Figure 4 – Main Hallway on 1st Floor

4.7.2. Number of Exits

The number of required exits depends on the occupant load. Since none of the floors have an occupant load of more than 500, two exits per floor is sufficient, as stated in the LSC 7.4.1.1 and 7.4.1.2.

The first floor of the PF has twenty-three (23) exits leading directly to the exterior of the building. Thirteen (13) of these exits are located in areas that are not available to all of the building occupants. The basement is served by two stairs; one stair is dedicated to the basement and the other provides access to all the floors. The exits are remotely located from each other, as directed by LSC 7.5.1.3.1. Reference Appendix D for all exit locations for the PF.

4.7.3. Exit Capacity Calculations

Egress capacity for the PF exits is prescribed in the LSC Table 7.3.3.1. for non-healthcare facilities, stairways are permitted to have 0.3 inches/person and level components can have 0.2 inches/person. Level components include doorways into the stairwell and outside discharge. To calculate whether or not the PF meets the prescriptive-based requirements, it is assumed that the occupant load is divided evenly amongst all exits. The exit capacity has to be greater than the occupant load of the floor divided by the number of exits.

Reference Appendix E for the egress analysis calculations. As shown in the table in Appendix E, the four stairs are the most restrictive components of all the egress systems. Therefore, the total calculated stairwell exit capacity for the PF is 605 people. The total building occupant load is 857 people and of that amount, 412 people can be deducted from the total since they would be exiting directly from any one of the twenty-three exits on the 1st floor. This would leave a total of 445 people using the stairwells which is less than the calculated capacity of 605 people. Based on the aforementioned information, the exit capacity is able to support the occupant load of the PF.

4.7.4. Total Building Evacuation Times – Hand Calculations

A hydraulic flow model from Chapter 13, Section 3 of the SFPE Handbook was used to estimate the total evacuation time for PF. The hydraulic model relies on the following assumptions:

All persons start to evacuate at the same time and travel time to the stairways/doorways is not analyzed.

- Occupant flow does not involve interruptions caused by evacuee decisions.
- The evacuees are free of impairments/disabilities that impede their movement.
- The flow through doorways and stairways was always maximized.
- The occupant load was distributed equally between exits. The required safe egress time (*RSET*) is equal to the sum of discrete time intervals, given by the equation:

$$RSET = t_d + t_n + t_{p-e} + t_e$$

Where:

t_d = Time from fire ignition to detection (will be combined with t_n in performance based section of this report)

t_n= Time from detection to notification of occupants (will be combined with td in performance based section of this report)

$t_{p\text{-}e}$=Pre-evacuation (aka Pre-movement time)

t_e = Time from start of purposive evacuation movement until safety is reached

The first step is to find the effective width of the stairway. The boundary layer for stairways, according to Table 3-13.1 in the SFPE Handbook, is 6” on each side, meaning there will be an effective width of 12” for each stairway. The stairs have a maximum specific flow of 18.5 persons/min/ft. (7/11 riser/tread), according to Table 3-13.5 in the SFPE Handbook. Based on these constants, the flow rate for the NE, NW, West, and South stairs are as follows:

$$F_{NE_{Stairs}} = (62\text{"-}12\text{"}) * (1ft/12\text{"}) * \left(\frac{18.5\,\frac{persons}{min}}{ft}\right) = 77\; people/minute$$

$$F_{NW_{Stairs}} = (61\text{"-}12\text{"}) * (1ft/12\text{"}) * \left(\frac{18.5\,\frac{persons}{min}}{ft}\right) = 75\; people/minute$$

$$F_{South_{Stairs}} = (61\text{"-}12\text{"}) * (1ft/12\text{"}) * \left(\frac{18.5\,\frac{persons}{min}}{ft}\right) = 75\; people/minute$$

$$F_{West_{Stairs}} = (46"\text{-}12") * (1ft/12") * \left(\frac{18.5\,\frac{persons}{min}}{ft}\right) = 52\,people/minute$$

The doors leading into and out of the stairways will be analyzed next. Since there is a bar between the doors, the effective widths will double, thus the doors will have an effective width of 24”. Doors and corridors have a maximum specific flow of 24 persons/min/ft., according to the same source. Based on these constants, the flow rate for the doors are:

$$F_{NE_{Stair\_Door}} = (72" - 24") * \left(\frac{24\,\frac{persons}{min}}{ft}\right) * (1ft/12") = 96\,people/minute$$

$$F_{NW_{Stair\_Door}} = (72" - 24") * \left(\frac{24\,\frac{persons}{min}}{ft}\right) * (1ft/12") = 96\,people/minute$$

$$F_{South\quad Stair\_Door} = (72" - 24") * \left(\frac{24\,\frac{persons}{min}}{ft}\right) * (1ft/12") = 96\,people/minute$$

$$F_{West\quad Stair\_Door} = (44" - 12") * \left(\frac{24\,\frac{persons}{min}}{ft}\right) * (1ft/12") = 64\,people/minute$$

The flow rate for the three stairs from the 2nd floor is limited by the maximum specific flow for the stairways. The time to evacuate from the 2nd floor is based on the occupant load determined earlier in the report and is shown below:

$$t_{NE_{Floors}-2nd} = \frac{(315\,people/3)}{77\,people/min} = 1.3\,min$$

$$t_{NW/South\_Floors\,2nd} = \frac{(315\,people/3)}{75\,people/min} = 1.4\,min$$

$$t_{NE/West_{Floors}-Basement} = \frac{(130\,people/2)}{52\,people/min} = 1.25\,min$$

Since the time to evacuate the basement stairs is less than the time it would take to evacuate the stairs for the 2nd floor, it does not need to be included in the overall evacuation. Another factor that was analyzed was whether the doors would be a limiting factor with people coming from the 2nd floor and the basement. The exiting time is equal to 1.4 minutes (NW/South 2nd floor stairs). The time it would take an occupant to get from the second floor to the first floor must be evaluated. The 1.4 minutes accounts for once the stairway starts queuing however, it takes time to get from the second floor to the first floor, as described in the SFPE Handbook. The speed of movement down the stairs would equal:

$$S = k - akD = 212 - 2.86 * 212 * 0.175 = 106 \text{ ft/minute}$$

The constants for stairs were found on page 3-379 in the SFPE Handbook. With this velocity, the travel time can be calculated since the travel distance between floors is around 38.2 ft. Thus, the travel time for an occupant moving from the second floor to the first would equal:

$$t_{2\ to\ 1} = \frac{38.2 ft}{106\ ft/min} = 0.36\ min$$

Returning to the RSET equation: $t_d + t_n + t_{p\text{-}e} + t_e$, the total building evacuation time can be calculated as shown in Table 8 below.

Table 8. Total Building Evacuation Time

Egress Equation Times	Production Facility Details	Time
Detection Time	The detection time is minimal during occupied hours (when occupants are alert and walking around). During unoccupied hours, smoke detectors are around the building so this time will still be minimal.	31 s
Alarm Time	If an occupant smells smoke or sees flames, there are pull stations at every exit. If a smoke detector alarms, the fire alarm will sound for the whole building.	0s
Pre-movement Time: Recognition & Response Times	This value is determined in the performance-based section of this report (Section 11.12.4). Fire Drills occur on an annual basis and false alarms are infrequent, thus the recognition time is minimal. PF will have a smaller response time than a building with visitors who don't know the building or require extra assistance.	36 s
Movement Time	Corridors have emergency lighting and exits are clearly marked with exit signs, so this time will again be minimal.	= 0.36min + 1.4 min = 1.76 min (106s)

RSET = 31s + 36s + 106s = 173s = **2.9 minutes**

According to the aforementioned hydraulic model values, the estimated time for evacuation of the entire building is approximately 2.9 minutes. However, one must consider that the values from detection time, alarm time, and pre-movement time are all estimates and can vary depending on the particular situation. In addition, travel time from a location on the floor to the exit stairway (on the 2nd floor and the basement) is not taken into account which would add more time. A safety factor was not added to the calculated RSET value above since the pre-movement time value is conservative based upon annual fire drills and infrequent false alarms at the PF. In conclusion, this is an optimal evacuation time for PF. The Pathfinder and FDS simulated evacuation times are provided in the following Section and Section 11.12.6 of this report.

4.7.5. Total Building Time – Computer Modeling (Pathfinder)

A computer model using Thunderhead Engineering's Pathfinder 2015 ® was generated to replicate evacuations at the PF. Pathfinder is an emergency egress simulator that allows the user to evaluate evacuation models. The basement, first, and second floor plans were imported into Pathfinder and rooms, stairways and doors were drawn manually. The second floor has a calculated occupant load of 315 people and the first floor has 412 occupants. These people have egress access from 13 to 23 exits that lead directly to the outside of the building. See Appendix H for Pathfinder screenshots and model egress time. There were some minor differences between the model and the actual building setup, a few of which are noted below:

- Only one egress door was modeled for lab rooms although all the lab rooms have two doors; however, in Pathfinder users would go through the lab to egress, which would not happen in real life. Therefore, less doors were added but that also created queues in rooms for people regressing.
- There are significantly less people occupying the building, so the long queue lines would not exist if an actual evacuation occurred based on the average number of people in the building (i.e., 140 people).
- Pre-movement times, detection and alarm times were not accounted for in the model.
- The areas were modeled as empty rooms and furniture will affect occupants' egress time.

The Pathfinder ® model predicted a total building evacuation time of 144 seconds (2.4 minutes) as shown in Appendix H. The Pathfinder evacuation time value compares nicely with the aforementioned hydraulic model value which estimated a total building evacuation time of 2.9 minutes.

4.7.6. Arrangement of the Means of Egress

4.7.6.1. Remoteness of Exits

Since the PF is protected throughout by an approved automatic sprinkler system, the minimum separation distance between two remote exits must be greater than one-third the length of the maximum overall diagonal dimension of the building, according to the LSC 7.5.1.3.3. The diagonal measured on the first floor (the greatest area) is equal to 330-ft, with

1/3 the diagonal equaling 110-ft. The closest main exits are 135-ft apart, thus greater than the minimum distance. The PF is compliant in regards to the arrangement of its exits.

4.7.6.2. Dead-Ends

The maximum dead-end distance allowed is 50-ft for both the LSC 7.5.1.5 and IBC 1020.4. There are no areas in the PF that exceed these dead-end distance requirements of the LSC and IBC.

4.7.6.3. Common Path of Travel

The maximum common path of travel allowed by the LSC Section 7.6 and IBC 1006.2.1 is 100-ft. There are no areas in the PF that exceed the maximum common path of travel distance requirements of the LSC and IBC. 4.7.6.4. Table 9 below shows the travel distance requirements taken from IBC Table 1017.2 and LSC Table A.7.6. All travel distance values are based upon an existing fully sprinklered building.

Table 9. Travel Distances (ft)

Occupancy	LSC	IBC	Actual
Business/B	300	300	163
Assembly/A-3	250	250	132
Industrial – General and high hazard	250	250	87
Storage – Low Hazard	No Requirement	No Requirement	-

Travel distances were measured from the furthest point within occupancy to the nearest exit. All travel distances within the PF comply with IBC and LSC requirements.

4.7.7. Horizontal Exits

There are no horizontal exits at the PF.

4.8. Exit Signs

Exit signs are required in the building in accordance with the IBC Section 1013.1 and LSC Section 7.10. Exit signs are required to be illuminated and readily visible. Refer to Appendix F for exit sign location drawings. The PF is in compliance with exit sign code requirements for both the LSC and IBC. Figure 5 below shows an example of a typical exit sign at the PF.

Figure 5 – Example of Exit Sign Location at Main Exit (North)

4.9. Summary

The arrangement, remoteness, and the number of exits for each level is acceptable. The exit capacity for each exit was determined to be greater than the occupant loads. The hydraulic model building evacuation time compared nicely to the Pathfinder simulated time. The building does not have any dead-ends and the maximum common path and travel distances were found to not exceed the code mandated values. Exit signs were determined to be in compliance with code requirements.

The activation of the fire suppression system will initiate egress from the building. The next section of this report discusses the design and operation of the fire suppression system.

5. Fire Suppression System

5.1. Water Tanks and Fire Hydrants

Kirtland Air Force Base (KAFB) has three main water tanks supporting fire suppression systems. The tank sizes are 750,000 and two 500,000 gallons. The PF is located in Tech Area I of Sandia National Laboratories which is the area of the Sandia campus which has the most developed water line system because of the high number of facilities in the area and population of building occupants. There are numerous fire hydrants installed around the PF as shown in Figure 6 below. NFPA 24 paragraph 7.2.1 states that hydrants shall be provided and spaced in accordance with the requirement s of the authority having jurisdiction. SNL uses a minimum distance of 100’ to the FDC, and other hydrants being located within 300’ of any location in the building.

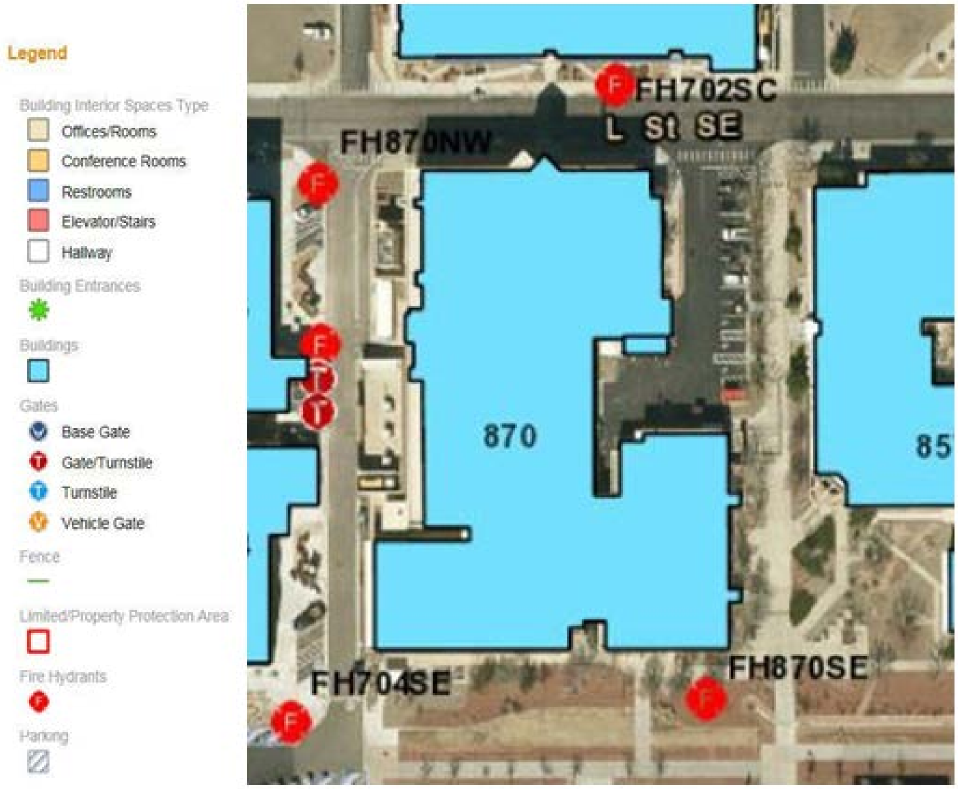

Figure 6 – Fire Hydrant Locations

5.2. Water Supply Analysis

The water supply supply and demand graph for the worst-case fire sprinkler demands is shown in Figure 7 below. The sprinkler systems were hydraulically designed to provide a density in accordance with ordinary hazard, Group 2 criteria. A minimum 500-gpm hose stream allowance has been included with the sprinkler flow demand in the design of all systems in the building (DOE Requirement). The graph clearly shows that the water supply is greater than the sprinkler system demand and is sufficient to provide ample water supply in case of a fire.

Water Supply Test Results and Three Largest Sprinkler Demands

Building:	Bldg. 870, Production Facility					
Location:	M Avenue					
Area:	I					
Area Protected		Density (gpm/ft²)or No. of Heads	Area(ft²)	Flow - gpm(no hose) / Flow - gpm(w/hose)	B.O.R. Pressure - psi / B.O.R. Pressure - psi	Hose Stream Allowance(gpm)
North Wing, 1st Floor West		0.20	3,000	988	50.02	500
				1488	50.02	
Cleanroom		0.20	1,977	499	56.04	500
				999	56.04	
West Wing		0.20	2,200	785	55.8	500
				1285	55.8	

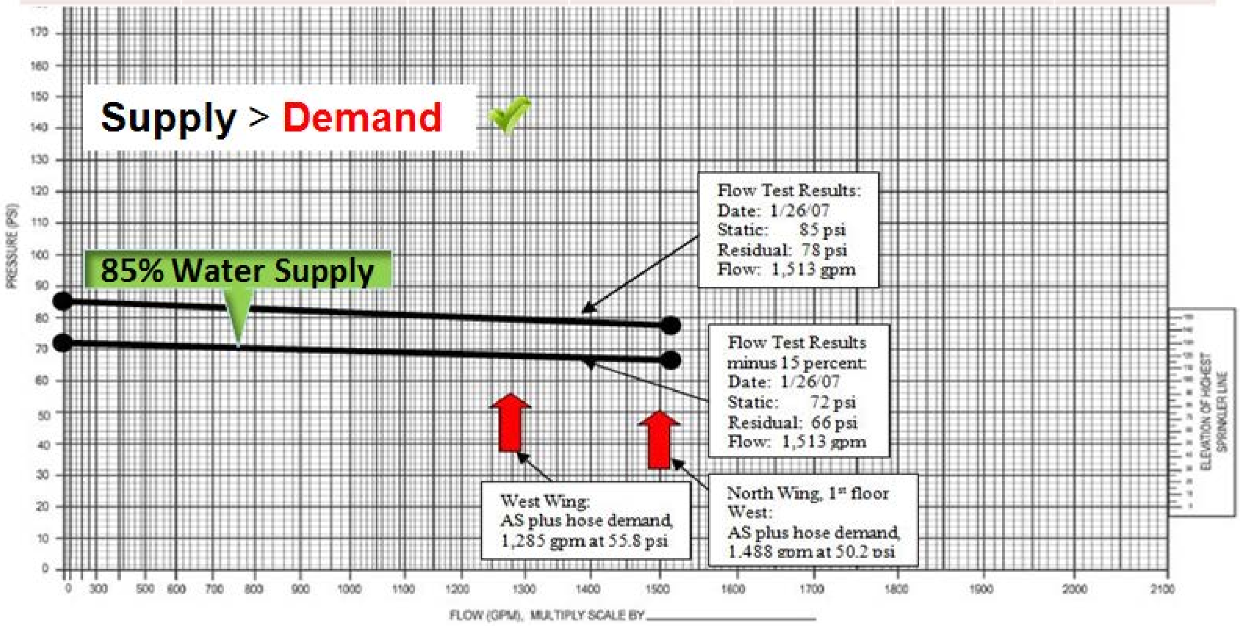

Figure 7 – Water Supply Graph Using Worst Case Sprinkler Demands

5.3. Automatic Sprinkler Protection

Automatic sprinkler protection is provided for the entire PF complex. It consists of an ordinary hazard system (DOE requirement) on maximum 130-ft^2 spacing per sprinkler with 165F 1/2-inch orifice sprinklers fed by a 6-inch wet-pipe valve. The sprinkler systems were hydraulically designed to provide a density in accordance with Ordinary Hazard, Group 2 criteria. A minimum 500-gpm hose stream allowance (DOE requirement) has been included with the sprinkler flow demand in the design of all systems in the building. Due to the need for functional independence between the East Wing prototyping area and the North Wing fabrication area, a separate riser and lead-in has been provided for the East Wing and North/West Wings. A new 8-inch lead-in was provided from the underground main to the riser for the East Wing. A post indicator valve (PIV) was provided for isolation of the lead-in, located approximately 25-ft south of the building to allow safe access in the event of a fire. A 4-inch freestanding fire department connection was provided south of the building. Figures 8 and 9 below show the PIV and Fire Department Connection (FDC) for the 8-inch lead in.

Figure 8 –Post Indicator Valve and FDC

Figure 9 – West Wing Riser

Sprinkler protection for the clean rooms, Final Assembly/Deposition/ Particulate Contaminate Control Area, Metalize Area, Cleaning Rooms, Inspection Room, Receiving and Inventory, Encapsulation and Development, Tube Testing, Chemical Technology and Metallurgy, and Furnace Area were hydraulically designed to provide a minimum density of 0.20-gpm/ft^2 over the most remote 3000-ft^2 using quick response pendant type sprinklers with a low-temperature rating (135F to 170F). All sprinklers are spaced on maximum 100-ft^2 spacing.

The Administrative Offices of the West Wing, Computer Room, and second floor Office and Conference Rooms protected by this system is capable of providing a minimum density of 0.18 gpm/ft^2 over the most remote 2,500 ft^2 utilizing standard sprinklers on a maximum 130-ft^2 /sprinkler spacing.

Sprinkler protection for the Clean Room, Hooded Room, Assembly Area, Metalize Area, Cleaning Room, Inspection Room, and Furnace Area were hydraulically designed to provide a minimum density of 0.20 gpm/ft^2 over the most remote 3000 ft^2 using quick response pendant type sprinklers with a temperature rating of 135°F to 170°F. All sprinklers are on a maximum 100 ft^2 per sprinkler spacing.

The Mechanical/Electrical Room has high temperature (286°F) sprinklers on a maximum 100 ft^2 per sprinkler spacing and was hydraulically designed for a minimum density of 0.20 gpm/ft^2 over the entire room area. Remaining portions of the East Wing protected by this system are capable of a minimum density of 0.15 gpm/ft^2 over the most remote 2,500 ft^2 utilizing standard temperature rated sprinklers on a maximum 130 ft^2 per sprinklerspacing. Automatic sprinkler protection is also provided in the Bunker using a wet-pipe arrangement with high-temperature rated sprinklers capable of a minimum density of 0.60 gpm/ft^2 over the entire respective building area. Hydraulic calculations for one of the most remote area of the second floor are located in Appendix H of this report.

Automatic sprinklers used within the facility are primarily Tyco/Grinnell Model TY-L Series, ½ in. orifice, and ordinary temperature sprinklers. Within the cleanrooms Central Omega Model C-1 sprinklers were used and they were replaced as part of the recall for that particular sprinkler.

Some of the cleanrooms within Bldg. 870 had ordinary-response, automatic sprinklers. Due to the high air velocities within the cleanrooms, quick response sprinklers are required and were installed in some areas in order to respond to a fire within an adequate time frame. A full set of sprinkler drawings are located in Appendix G of this report.

Based on the review of the fire sprinkler drawings, the PF is NFPA 13 code compliant with the location of fire sprinkler devices. The PF has a fire protection assessment conducted every three (3) years and there are no major open findings for deficiencies related to the fire sprinkler design and installation. Sprinkler device cut-sheets are provided in Appendix H.

5.4. Fire Fighting Systems

The facility is provided with Class I standpipes in the stairwells. These standpipes are classified as manual standpipes, since the available water supply will not provide 100 psi at the top of the riser. Portable fire extinguishers of the proper type and size are properly located throughout the building. There are three hydrants located near this structure. One is approximately 25-ft south, the second is approximately 42-ft north, and the third is approximately 55-ft west of the building. These three hydrants will adequately cover all areas of this building; therefore, additional fire hydrants for this facility are not required to meet the 300-ft spacing requirement.

5.5. Sprinkler System Hydraulic Calculations

There are no existing hydraulic design calculations available for the PF. The sample hydraulic calculation performed is assumed to be one of the most hydraulically demanding scenarios for the facility. It assumes that the area protected by riser #1 is on fire. The size of the remote area is 1500 sq.ft. And the design density is 0.20 gpm/ft^2. Figure 10 illustrates the area and the sprinkler piping network.

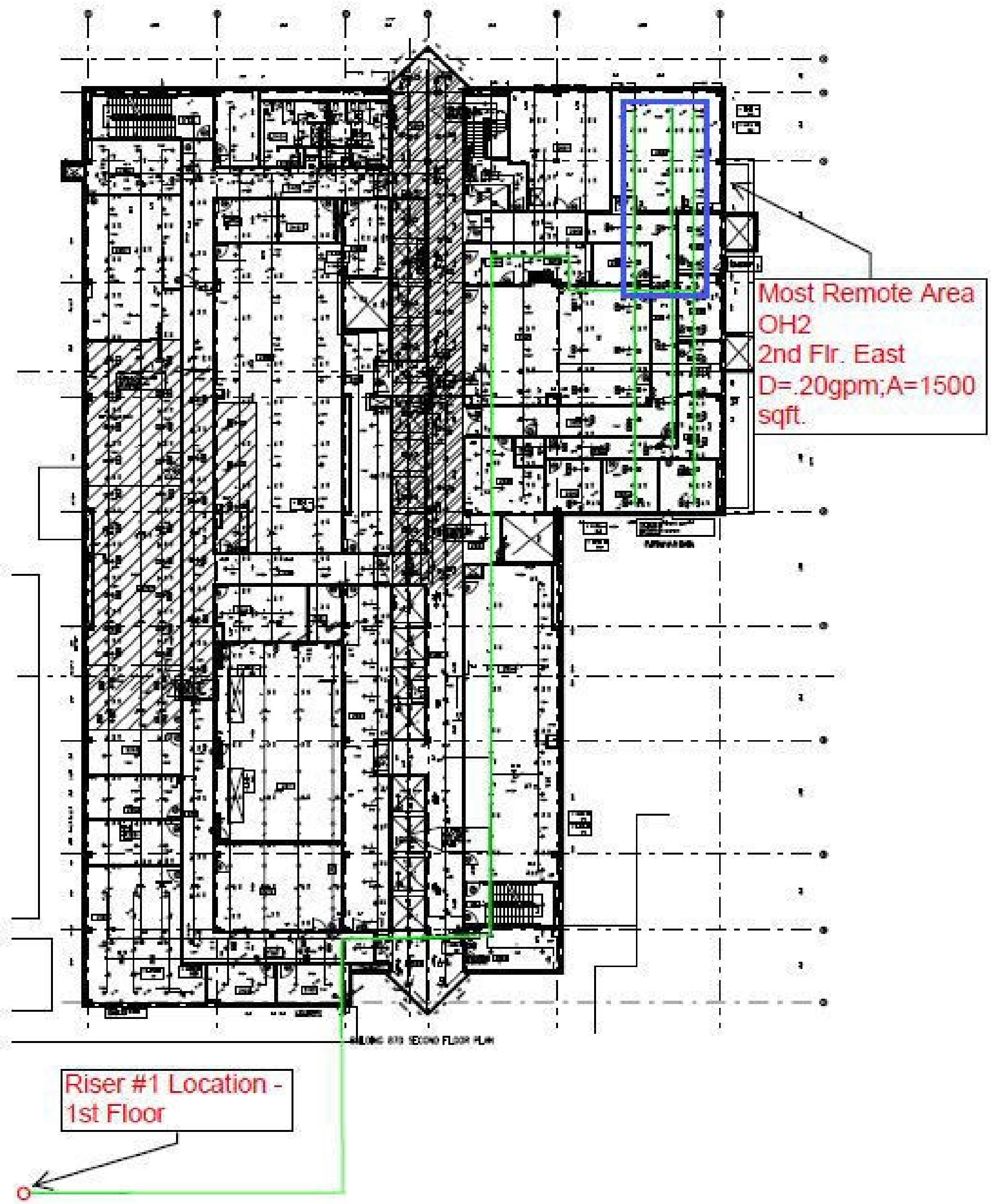

Figure 10 – Hydraulically Remote Area – 2nd Floor

5.6. Inspection, Testing, and Maintenance

Inspection, Testing and Maintenance is performed in accordance with NFPA 25. The frequency of inspections and testing can be found in Section 8 of this report.

5.7. Summary

The PF is located in an area of the laboratory that has the most developed water line system. There are also numerous fire hydrants installed around the building. The water supply serving the building was tested and found to be able to provide more than the building's sprinkler system demand and is therefore deemed more than adequate for fire suppression purposes.

There are some noted deficiencies such as no existing hydraulic sprinkler system calculations, current drawings, and updated waterflow test documents. A waterflow test has been scheduled in the nearterm and the other deficiencies will be corrected as scheduling permits.

The fire sprinkler system for the PF is robust and will provide a sufficient amount of water to suppress most anticipated fires in the building. The next section of this report discusses the design and operation of the fire alarm system.

6. Fire Alarm System

6.1. General Description

The building's fire alarm system is monitored by a proprietary supervising station. The station is located on Kirtland Air Force Base (KAFB) and monitors all of the SNL Albuquerque location. The station utilizes a Digital Alarm Communicator Receiver (DACR) to receive alarms from Digital Alarm Communicator Transmitters (DACT) located inside the fire alarm control panel (FACP). The FACP is an Edwards Signaling Technology (EST) Quick Start (QS4) Intelligent Control Panel. The panel can support up to 1,000 intelligent detectors and modules along with 48 conventional Class B or 40 Class A/B initiating device circuits (IDC). Appendix I includes all the fire alarm equipment/device manufacturer datasheets. The FACP and Power Expander Panels are shown in Figure 11 below.

Figure 11 – FACP and Power Expander Panels

6.2. Operating Characteristics

All fire alarm, trouble, and supervisory signals are directed to the FACP which has a radio transponder that transmits them to Sandia's proprietary receiving system; they are then retransmitted to the Kirtland AFB Fire Department for their disposition and subsequent response, as necessary, in accordance with NFPA 72, 26.4.6.6. Figure 12 below shows the Fire Alarm System Functional Matrix.

SYSTEM OUTPUTS

- A ACTUATE COMMON ALARM VISUAL AND AUDIBLE INDICATOR AT FACP
- B DISPLAY ALARM DEVICE ADDRESS POINT AND LOCATION DESCRIPTION
- C ACTUATE SUPERVISORY VISUAL AND AUDIBLE INDICATOR AT FACP
- D DISPLAY SUPERVISORY DEVICE ADDRESS POINT AND LOCATION DESCRIPTION
- E ACTUATE COMMON TROUBLE VISUAL AND AUDIBLE INDICATOR AT FACP
- F DISPLAY TROUBLE CONDITION
- G TRANSMIT SUPERVISORY SIGNAL TO CENTRAL STATION
- H TRANSMIT ALARM TO CENTRAL STATION
- I ACTUATE BUILDING NOTIFICATION DEVICES
- J TRANSMIT TROUBLE TO CENTRAL STATION
- K SWITCH HVAC EQUIPMENT CONTROLS TO FIRE ALARM MODE
- L RELEASE MAGNETICALLY LOCKED DOORS
- M SILENCE PANEL AND FACILITY AUDIBLES AND VISUALS
- N CONTROL PANEL RETURNS TO NORMAL (AUDIBLES AND VISUALS STOP)
- O RECORD EVENT IN FACP SYSTEM MEMORY

	FACP SYSTEM INPUTS	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	MANUAL PULL STATIONS	●	●						●	●			●			●
2	AREA SMOKE AND HEAT DETECTORS	●	●						●	●			●			●
3	SPRINKLER WATERFLOW	●	●						●	●			●			●
4	OPEN CIRCUIT, GROUND FAULT					●	●				●					●
5	SPRINKLER TAMPER SWITCH / PIV			●	●			●								
6	DUCT DETECTORS			●	●			●				●				
7	NAC POWER SUPPLY TROUBLE CONDITION					●	●				●					
8	DACT FAIL / TELECOM FAIL					●	●				●					●
9	FIRE ALARM AC POWER FAILURE / ABNORMALITY					●	●				●					●
10	FIRE ALARM SYSTEM LOW BATTERY / BATTERY CIRCUIT FAIL					●	●				●					●
11	SYSTEM SILENCE					●	●				●			●		
12	SYSTEM RESET														●	
13	ANCILLARY CONTROL PANELS (HSSD)			●	●			●				●				

Figure 12–Fire Alarm System Functional Matrix

6.3. Types of Devices

Fire detection devices on a Signaling Line Circuit (SLC) or IDC shall be an NFPA 72 Class A circuit per Sandia Spec. 13852 Sect. 1.06. According to NFPA 72, 12.3.1, a Class A pathway includes a redundant path, continues to operate past a single open or a single ground fault, and conditions that affect the intended path result in a trouble signal. Figure 13 below shows some of the typical fire detection and initiating devices found at the PF.

Figure 13 – Fire Alarm Detection and Initiating Devices

The PF contains various forms of fire detection devices throughout the building. There is not a full smoke detection coverage requirement for the building per IBC 907.2 and NFPA 72, 17.5.3.2. Smoke/Duct detectors exist to specific areas to activate a fire alarm safety function per IBC 907.3. These fire alarm safety functions include controlling door releases, shutting down the HVAC (smoke-control function), shutting down toxic gas panel. Smoke detectors are also located to protect the FACP and FATCs per IBC 907.4.1 and NFPA 72, 10.4.4. Duct detectors are located in the supply and return air ducts for unit shutdown (i.e., smoke control), and vanetype water flow detectors are located n the sprinkler risers. Heat detectors or specialty harsh environment smoke detectors are used instead of the photoelectric smoke detectors in areas that are smoky, dusty, humid, or have extreme temperatures. A High-Sensitivity Smoke Detection (HSSD) system is also located in clean room areas. Manual pull stations are located every 400-feet in the corridor, and every 150-feet along the chemical transport route per IBC 415.10.2. Manual pull stations are located near every exit of the building even though IBC 907.2 only requires a minimum of one pull station. The pull stations are located within 5 feet of every exit per IBC 907.4.2.1. Manual pull stations are installed 42-48 inches above the finished floor per IBC 907.4.2.2. Table 10 below provides a detailed list of the fire alarm initiating devices installed at the PF.

Table 10. Fire Alarm Initiating Devices

Initiating Devices					
Device	**Manufacturer**	**Locations**	**Number**	**Specifications**	**Supervisory or Alarm?**
Duct Detector	ESTSIGA-SD Signature Series Super Duct	Return air, supply air	16	0.79%to2.46% obscuration/ft.	Supervisory
Flow Switches	EST Dual Monitor Module	Riser Rooms	1		Alarm
Heat Detector	ESTSIGA-HRS, Heat Detector	Elevator pits, elevator mechanical rooms and top of elevator shaft	45	Alarm sat 135˚F(57˚C)orRORof15˚F/min(9.4˚C)	Alarm
Pressure Switches	EST Dual Monitor Module	One for each riser	3		Alarm
Pull Station	ESTSIGA-278 Pull Station	Next to all exits, next to all entrances to stairways	37		Alarm
Smoke Detector	ESTSIGA-PS Smoke Det.	Elevator lobbies and shafts, unoccupied telecom rooms, lunch rooms and by FACP	87	0.67% to3.77%/ft.	Alarm
Sprinkler Supervisory (Tampers)	EST Dual Monitor Module	Two on each floor for each control valve and in chemicals to rage area for Anti freeze loop	8		Supervisory

6.4. Location, Spacing, and Placement of Devices

The PF FACP and specific locations for the fire alarm devices can be found in Appendix J - Fire Alarm Shop Drawings. The PF is in full code compliance regarding the installation and placement of fire alarm initiating devices. See below for a partial list of code requirements for device placement:

- IBC 2015 Section 404.4 – Fire Alarm System. A fire alarm system shall be provided in accordance with Section 907.2.14 and the PF meets this requirement.
- IBC 2015 Section 907.4.1 – Protection of Fire Alarm Control Unit. In areas not continuously occupied, a single smoke detector shall be provided at the location of each fire alarm control unit, notification appliance circuit power extenders, and supervising station transmitting equipment. The PF meets this requirement. A smoke detector is

provided in each one of these areas. (Note: Duct smoke detectors are also installed where required by NFPA 90A.).
- IBC 2015 Section 907.4.2.1 – Location. Manual fire alarm boxes shall be located not more than 5 feet from the entrance to the exit. The PF meets this requirement. The PF has 37 pull stations in required locations. (Note: NFPA 101 9.6.2.3 has the same requirement.)
- NFPA 101 Paragraph 9.6.2.5 – Additional fire alarm boxes shall be located so that, on any given floor in any part of the building, no horizontal distance on that floor exceeding 200 ft shall need to be traversed to reach a manual fire alarm box. The PF meets this requirement upon review.
- NFPA 101 Paragraph 9.6.2.8 – Where a sprinkler system is installed, an automatic detection and alarm system initiation input shall be provided that operates when the flow of water is equal or greater than that form a single automatic sprinkler. Each of the three risers in the PF has water flow/pressure switches with monitor modules which are connected to the fire alarm system. Upon any water flow condition, the fire alarm system sounds a general fire alarm throughout the facility.
- NFPA 72 Chapter 18 spacing requirements for smoke and heat detectors: PF meets code

6.5. Fire Alarm Signal Disposition

The fire alarm system at the PF communicates to a proprietary supervising station at Sandia National Laboratories. The reason this station, called The Phoenix, is this type is that it is monitored by Sandia emergency operations, maintenance and fire protection engineering all of who have a financial stake (from a company perspective in the protected property (buildings). The central station is monitored by a workstation in Sandia's maintenance building. The manager of the Fire Protection maintenance department also has a monitor in his office that he watches throughout the day. Finally, the Kirtland Air Force Department receives the signals from The Phoenix at their Honeywell central receiving station. There is no Emergency communication system installed for the PF.

If an alarm is received at the PF or any other Sandia building, then the Kirtland Air Force Base Fire Department will respond to the building and extinguish the fire as appropriate. If a trouble is received at the supervising station, then the fire protection maintenance manager will dispatch personnel to troubleshoot the system. If a supervisory signal is received then Sandia emergency operations will investigate and contact Sandia facilities if need-be. In the event of an alarm at the PF, key management personnel will also be notified and coordinated with to avoid shutting down production or evacuating personnel if need-be.

6.6. Types of Alarm Notification Appliances

The standard notification appliance located throughout the PF is a Wheelock series wall horn/multi-candela setting strobe appliances. There are some variations to this depending on where they are located. In the clean rooms, audible only devices are installed as not to interfere with the manufacturing process (which a strobe would do with its “harsh” light). Figure 14 shows a typical notification device for the PF. There are a couple strobe only devices located in the facility as well. Table 11 below provides a detailed list of the fire alarm notification devices installed at the PF.

Table 11. Fire Alarm Notification Devices

Fire Alarm Notification Devices				
Device	**Manufacturer**	**Locations**	**Number**	**Specifications**
Multitone Horn/ Strobe	Wheelock MT-24MCW	Throughout the building as required to achieve the proper coverage.	75	Varies, initially set to 15cd
Strobe	Wheelock RSS-24MCW-FR multi- candela strobe	All common areas (e.g. restrooms, conference rooms, break areas, corridors, hallways, stairways, lobbies), open areas with calculated occupant loads of 10 or more occupants, and in locations with a high ambient sound level (e.g. mechanical rooms)	27	Varies, initially set to 15cd
Exterior Strobe	System Sensor SpectrAlert Advance, Model SRHKR, weatherproof	At main entrance of the building that is readily visible to emergency responders for indicating when the building fire alarm system is in ALARM condition	1	Set to 75cd

Figure 14– Fire Alarm Notification Device

6.7. Location, Spacing, and Placement of Devices

Most of the occupied areas of the facility have coverage with a notification appliance. NFPA 72 makes it clear that it doesn't dictate exactly where an appliance is located for audible and visual notification purposes. See the relevant NFPA 72 excerpts below:

- **18.4.1.4.1** The designer of the audible notification system shall identify the rooms and spaces that will have audible notification and those where audible notification will not be provided.
- **18.4.1.4.2** Unless otherwise specified or required by other sections of this Code, the required coverage area for visible occupant notification shall be as required by other governing laws, code, or standards. Where the other governing laws, codes, or standards require audible occupant notification for all or part of an area or space, coverage shall only be required in occupiable areas as defined in 3.3.178.
- **18.4.1.4.3** The sound pressure levels that must be produced by the audible appliances in the coverage areas to meet the requirements of this Code shall be documented by the system designer during the planning and design of the notification system. The greater of the expected maximum sound pressure level having duration of at least 60 seconds shall also be documented for the coverage area by the system designed to ensure compliance with 18.4.3, 18.4.4, 18.4.5, or 18.4.6 for the coverage area.
- **3.3.178 Occupiable Area.** An area of a facility occupied by people on a regular basis.
- **18.5.2.1** The designer of the visible notification system shall document the rooms and spaces that will have visible notification and those where visible notification will not be provided.
- **18.5.2.2** Unless otherwise specified or required by other sections of this Code, the required coverage area for visible occupant notification shall be as required by other governing laws, code, or standards.

Based on the review of the fire alarm drawings, the PF is NFPA 72 code compliant with the location of notification appliances. Sandia National Laboratories does not require individual audible or visual notification appliances in individual offices. It also does not require them in storage rooms. Sandia requires notification appliances (both visual and audible) in conference rooms. Acceptance testing was performed for the facility and it was documented that the sound pressure levels of the appliances did not exceed 110dBA (per NFPA 72 18.4.1.2) and that they were at least 15dBA above any commonly accepted values of ambient noise levels throughout the facility (for business space, lab space, etc.). NFPA 72 paragraphs 18.4.8.1, 18.5.5.1, and 18.5.5.2 cover the mounting installation requirements for notification appliances. One of these requirements is to install wall mounted notification appliances such that entire lens is not less than 80 in. and not greater than 96 in. above the finished floor. The PF has a fire protection assessment every three years and there are currently no open findings for any deficiencies related to the fire alarm design and installation.

6.8. Secondary Power

Secondary power is provided for the PF fire alarm system via batteries located below the panel. Batteries are also provided for the Power Supply Panels. The design of the batteries follows the requirements in NFPA 72 paragraph 10.6.7.2.1 which states the secondary power supply must have the power capacity for 24 hours of standby operation and 5 minutes of operation in alarm mode Sandia uses lead-acid type batteries and has them routinely replaced by the fire alarm maintenance crew if the battery is more than 4 years old.

6.8.1. Adequacy of Secondary Power

The quantity of devices and NACs in the PF was extrapolated from the Sandia database and contract drawings. Manufacturer cut sheets were used to determine the required secondary power requirements. Using the requirements of NFPA 72 10.6.7.2.1, the calculated required amp-hours (AH) of the secondary power supply is 10-AH for the main FACP. The provided secondary supply capacity for the PF FACP is 12-AH, therefore the secondary power is adequate. The aforementioned battery supply requirements include a safety factor. The results of the battery supply calculations for the FACP and the four Power Supply Panels as well as voltage drops are provided in Appendix K of this report.

6.9. Smoke Control

The building contains a 2-story communicating space (aka, Atrium by current codes) connecting the 1st and 2nd Floor levels. In accordance with the 2015-IBC, an “atrium” is defined as an opening connecting two or more stories other than enclosed stairways, elevators, hoist ways, escalators, plumbing, electrical, air-conditioning or other equipment, which is closed at the top and not defined as a mall. Section 404.5 of the 2015-IBC Exception states that smoke control is not required for atriums that connect only two stories. In accordance with Section 404.6 of the IBC (2015 Ed.) and Section 8.6.7 of NFPA 101 (2015 Ed.), atrium spaces shall be separated from adjacent spaces by a 1-hour fire barrier.

Previous editions of the building code, including the 1991 UBC (code-of-record), defined an atrium as an opening connecting *three* or more stories, therefore the building did not have to meet atrium requirements at the time of construction; this type of area was referred to as a communicating space between floors. In accordance with Section 1706 and Table 17-A of the 1991 UBC, the communicating space was designed as an area for evacuation assistance with a one-hour fire-resistance rating. Therefore, the one-hour fire resistive corridors that are part of this atrium space, as well as the continuation of these corridors to the building exits, will be maintained. This passive fire protection feature has been retained to comply with the communicating space provisions of the 1991 UBC (code-of-record) and the current atrium provisions of the 2015-IBC.

Smoke movement into other areas of the building is controlled by HVAC duct-mounted smoke detectors and their interlocking damper closure and unit shutdown upon sensing smoke. The intent of this action is to control and/or limit the amount of smoke spread into other parts of the building.

6.10. Summary

The building's fire alarm system has been designed and installed per NFPA 72, the LSC, and IBC requirements. The fire alarm system has both manual and automatic devices installed. The alarm notification system consisted of horn or horn/strobe type devices.

The next section of this report discusses the structural fire protection systems for the PF.

7. Structural Analysis

7.1. Structural Fire Protection

The primary steel structure for the PF consists of steel wide-flange columns supporting steel wide-flange girders, beams, and joists. Only a small percentage of the primary steel structure is protected by spray applied fire-resistive material (SFRM); the SFRM is not a requirement since this building is classified as Type II-B noncombustible construction. Structural drawings are provided in Appendix L of this report. Building construction elements for the PF consist of a concrete slab on grade foundation and non-protected steel frame superstructure. Exterior walls at the East and West Wings are coated with 4-in. thick isocyanine form exterior mounted insulation covered by ¼-in. thick cementicious stucco covering. The roof assemblies of the facility are constructed of a single-ply membrane system over rigid insulation supported by a metal deck with an FM Type I-90 wind uplift rating and a 20-psf design live load. Additional design loads are shown in Figure 15. Roof framing members are sloped to provide positive drainage. The roof assembly is Class II insulated metal deck supported by unprotected steel beams and trusses.

DESIGN CRITERIA:

LOADS PER DOE ORDER 6430.1A AND UCRL-15910.
GENERAL DESIGN CRITERIA AS FOLLOWS:
FACILITY USE CATEGORY: LOW HAZARD
FIRST AND SECOND FLOOR DEAD LOADS:
5" SLAB: 56 PSF
PARTITIONS: 20 PSF
SUSPENDED MECH. ELECT. AND ARCH.: 20 PSF
ROOF LIVE LOAD: 20 PSF
ROOF JOIST CONCENTRATED LOADS:
AT ANY PANEL POINT: 1,000 LBS
BETWEEN PANEL POINTS: 100 LBS
SECOND FLOOR LIVE LOAD: 125 PSF
FIRST FLOOR LIVE LOAD: 125 PSF
BASEMENT FLOOR LIVE LOAD: 200 PSF
FLOOR JOIST CONCENTRATED LOADS:
AT ANY PANEL POINT: 2,000 LBS
BETWEEN PANEL POINTS: 200 LBS

WIND LOAD (REF. ASCE 7-88):
BASIC WIND SPEED: 78 MPH
IMPORTANCE FACTOR: 1.07
EXPOSURE FACTOR: C
SEISMIC LOAD (REF. 1991 UBC):
IMPORTANCE FACTOR: 1.25
Z: 0.22
C: 3.0
RW:
NORTH/SOUTH BRACED FRAMES: 6
EAST/WEST MOMENT FRAMES: 6
SEISMIC ZONE: 2B

VEHICLE LOAD (SHIPPING/RECEIVING AREA ONLY):
5,000 POUND CAPACITY FORK LIFT
WITH 13,000 POUND LOADED AXLE LOAD

Figure 15 – Structural Design Loads from Record Drawings

The building floor for the East and West Wings is a reinforced 5-in. concrete slab on grade. The floor of the North Wing is a reinforced 5-in. concrete floor slab. Record drawings show that the floor/ceiling assemblies in the basement area were intended to be constructed to UL Design No. D501 (using layers of gypsum to protect the steel) and/or P701 (using spray applied fire-resistive material - SFRM) to provide one-hour fire resistive ceilings for the exit corridor. However, the UL Designs were not followed properly (i.e., – SFRM location, thickness, etc.) so the floor/ceiling assemblies can't be credited as providing the required occupancy separation or exit corridor protection. The original Group H areas were re-classified as Group B occupancies because the SFRM could not be credited. Unprotected steel column and beam construction was observed in many areas during a recent site visit confirming the Type II-B construction. In addition, record documents for this building indicates it's constructed entirely of Type II-B noncombustible materials in accordance with the 2015-IBC. Figure 16 shows unprotected steel beams and beams with SFRM applied.

Figure 16 – Unprotected and Protected Steel Beams

8. Inspection, Testing, and Maintenance

8.1. Inspection and Testing

Sandia has its own in-house fire protection maintenance crew. This crew is divided up into three crafts: fire sprinkler, fire alarm, and fire extinguisher. The fire alarm crew handles all inspection, testing, and maintenance (ITM) for Sandia's fire alarm systems. Sandia building occupants can submit service requests for anything they notice wrong on the system. For example, a blocked strobe or audible warning not loud enough during a fire drill. In this fashion, the occupants are the daily basic inspection check for the system. For testing, each fire alarm system is commissioned in conjunction with the fire protection engineering department to ensure the systems meet code and function as designed before being accepted. For testing as part of preventive maintenance requirements, please reference the next section.

8.2. Preventive Maintenance

NFPA 25 (2014 Edition) is the governing code for fire suppression system testing requirements for this discussion. At Sandia National Laboratories, the ITM requirements of fire protection systems has been automated into a software program called Maximo which creates work orders for maintenance staff to perform work in the field. These work orders are referred to as PM checklists which stand for preventative maintenance checklists. These PMs (for short) are divided into four per year, each of which incorporates requirements from NFPA 25. There are two quarterly PMs, a semiannual PM, and an annual PM per year. The NFPA 25 semi-annual requirements are placed on that PM (such as verifying that a water flow signal from the inspector's test is received at the fire alarm control panel), the quarterly NFPA 25 requirements on that PM (such as visual inspection of alarm devices), and the annual NFPA 25 requirements on that PM (visual inspection of sprinkler heads). The Sandia fire alarm maintenance team performs a yearly preventive maintenance (PM) on each building that has a fire alarm system. This PM checklist has been made by fire protection engineering to incorporate all the ITM requirements from NFPA 72. Once completed these PMs will be routed to a Sandia fire protection engineer for review and disposition. If there are any discrepancies or follow-up repairs needed, the Sandia FPE makes sure that work gets done in the following few months. By the time the next annual PM occurs, all follow up actions and repairs from the previous year should be complete. A typical PM checklist is provided in Appendix M.

9. Emergency Management

9.1. Emergency Access

The PF is located within the TA-I security fence with property security clearance required to access the facility. Entrance into the East Wing and into the cleanrooms of the North Wing area is also access controlled. The building is continuously occupied during regular business hours. The security department and the maintenance personnel have keys to access the locked mechanical/electrical areas. Fire department vehicle access is provided on all sides of the building by paved roadways. The closest fire hydrant is approximately 50-ft west of the of the fire department connection on the south side of the building and approximately 40-ft from the standpipe and fire department connections on the north side of the building. The power for the building can be disconnected at the substation, and the shut-offs for the hydrogen and liquid nitrogen systems are located at the storage tanks.

9.2. Emergency Organizations

9.2.1. Evacuation Teams

An evacuation team for the PF has been organized and based upon the conversations with the Building Coordinator is in compliance with the Corporate Fire Protection Procedure for *Building Evacuation and Fire Teams*.

9.2.2. Fire Department

The Fire Department response time to the PF is approximately three to five minutes depending on road and traffic conditions, as estimated by the Kirtland Fire Department. The closest fire station to PF is Station 1, which is approximately 1½ miles northwest of the facility.

9.2.3. Emergency Documents

A Pre-Fire Planning program has been developed for the PF.

10.2.4. Disposition of Signals

If an alarm is received at the PF or any other Sandia building, then the Kirtland Air Force Base Fire Department will respond to the building and extinguish the fire as appropriate. If a trouble is received at the supervising station, then the fire protection maintenance manager will dispatch personnel to troubleshoot the system. If a supervisory signal is received then Sandia emergency operations will investigate and contact Sandia facilities if need-be. In the event of an alarm at the PF, key management personnel will also be notified and coordinated with to avoid shutting down production or evacuating personnel if need-be.

10. Prescriptive-Based Analysis Summary

Based upon the aforementioned site surveys, code verification, and review of record documents, the PF meets the intent of the prescriptive-based requirements of the 2015-IBC and the LSC. There still remain a few housekeeping and administrative issues that need to be addressed such as:

- Keeping exits clear of obstructions and combustibles.
- Enforcement of administrative controls to keep rated doors closed
- Limit the use of flammable and combustible liquids

11. Performance-Based Analysis

11.1. Disclaimer

The following performance-based analysis uses hypothetical scenarios to analyze the building for life safety. The scenarios are intended to be representative of hazards that exist in laboratory type buildings in general. The scenarios are not intended to identify the size and location of actual fire hazards. The information in this report is meant to supplement frequent inspections of the building fire protection system and good housekeeping habits in order to maintain the optimum level of safety for the occupants and the building. The fire hazards, calculation assumptions, and pass/fail criteria used for each scenario are conservative in nature in order to provide a factor of safety to the occupants of the building.

11.2. Introduction to Performance-Based Egress Analysis

The performance-based analysis is another way determining the life safety of a particular building; it provides alternatives to how the prescriptive parts of the code can be achieved. With more flexibility also comes more risk of human error by poor model design, inappropriate interpretation of the goals, objectives level of safety, appropriate fire scenarios, assumptions, and safety factors. A performance-based design can be used to prove an equivalent level of safety if a specific building or life safety code was not met or the building contains unique features not typically covered by code requirements. A performance-based analysis requires special consideration when choosing fire scenarios and their respective performance criteria. The fire scenarios must accurately represent fire hazards that can potentially occur in the building. The performance criteria must be set to an appropriate threshold in order to ensure life safety while not being too stringent to make the fire scenarios impossible to pass. The fire protection engineer should state all assumptions and references in order to give the AHJ confidence in the analysis.

11.3. Design Fire Scenario Considerations

The following fire scenarios were considered for what could be considered a credible, worst-case fire for the structure:

- Local Fire
- Test apparatus catching fire
- Chemical spill fire
- Atrium, large volume space, high ceiling
- Fully developed, post-flashover fire
- Small/medium compartment fire

The performance-based analysis consisted of ensuring the fire protection systems would perform under the most *likely* and *statistically most significant* fire scenarios for this type of building (concentrated office area, laboratory and industrial)

The systems must protect all occupants to safely egress and prevent the fire from spreading beyond the room of origin.

NFPA 101, Section 5.5, has the following eight Design Fire Scenario types:

1. Occupancy Specific/activity related
2. Ultrafast-developing fire in primary means of egress
3. Normally unoccupied room
4. Concealed space next to large unoccupied room
5. Slowly developing fire, shielded from fire protection
6. Most severe Fire/Largest fuel load
7. Outside Exposure Fire
8. Ordinary combustibles/ineffective-unreliable fire protection

11.4. Design Fire Scenarios

Fire Scenarios 1A and 1B: Kitchen Appliance Fire (LSC Design Fire Scenarios 1 and 8)

Quick Overview

- Location: 1st Floor Kitchenette
- Electrical malfunction is the 3rd leading cause of non-residential fires [1]
- Slow to Moderate-developing fire (LSC)
- Normally unoccupied kitchenette
- Fire caused by ignition of a microwave oven and secondary ignition sources are a wood table and old-style coffee maker
- Scenario 1A - Sprinklers will be impaired, however smoke detectors and horn/strobe devices will be active
- Scenario 1B – Sprinklers will not be impaired

The following Design Fire Scenarios were considered, but not evaluated due to time constraints:

- Atrium fire
- Cleanroom lab coat fire
- Lab test apparatus fire
- Wood pallet fire on the loading dock
- Flammable or combustible gas fire
- Forklift fire
- Combustible commodity fire in a stairwell
- Portable evaporative cooler fire inside the loading dock area

The kitchen appliance fire scenarios evaluated in this report, are considered the statistically most significant [1] of any of the above referenced possible scenarios. The next potentially significant fire scenario for the PF would be a lab test appraratus fire and would have been analyzed if time permitted.

11.5. Codes and References

SFPE Engineering Guide to performance-Based Fire Protection, 2nd Edition
SFPE Handbook of FPE, 4th and 5th Editions (SFPE HB)
2015 Edition, NFPA 101 Life Safety Code (LSC): Chapter 5

11.6. Facility Description

The unique building characteristics to the PF building was evaluated in order to determine the most appropriate fire scenarios. The PF building is a multi-program laboratory where various research efforts are being conducted throughout the building. The building is composed of office space, cleanrooms, and laboratory areas. The laboratories contain small amounts of chemicals which are stored in flammable liquid storage cabinets when not in use.

11.7. Building Occupant Descriptions

The majority of the occupants at the PF are engineers, scientists, and staff members who work in the building five days a week. High-school and college interns work in the building year-round and especially in the summer. These interns can be less familiar with the building and may be as young as sixteen. All PF occupants are able-bodied and capable of a reasonable egress time. Visitors to the building may have physical disabilities that could decrease their movement times, such as being wheelchair bound, however there would only be a small number of individuals requiring increased movement time.

11.8. Project Scope

The performance-based analysis will consist of ensuring the fire protection systems for the PF building will perform through two fire scenarios. The systems must protect all occupants to safe egress and prevent the fire from spreading beyond the area of origin. The primary stakeholders are the building owner, the AHJ (DOE), the Building and Fire Safety (BFS) department, the tenants, the building operations and maintenance, and the emergency responders. The aforementioned fire scenarios were chosen based on the building and occupant characteristics. The performance criteria are established from the design goals and objectives. The RSET is calculated using the method outlined in the SFPE handbook as well as the use of the egress computer model Pathfinder ®. The fire scenarios will be modeled using the Fire Dynamic Simulator (FDS) ® program.

11.9. Fire Protection Goals

The SFPE Engineering Guide to Performance Based Design [2] and the stakeholders' objectives were used to define the goals of the design project.

- Life Safety: Minimize fire-related injuries and prevent undue loss of life.
- Property Protection: Minimize fire related damage to the building and its contents
- Mission Continuity: Minimize undue loss of operations and business-related revenue due to fire-related damage.

The goals are intended to be broad statements about how a building is supposed to perform under a given fire scenario.

11.10. Stakeholder and Design Objectives

The stakeholders' objectives are intended to describe the maximum level of damage that they would be able to tolerate. After the stakeholder's objectives have been determined, it is necessary to create design objectives by determining what aspects of the building need to be protected. The design objectives include acceptable fire conditions that need to be maintained in order to meet the stakeholders' objectives.

Stakeholder's Objectives:

- Life Safety: Allow safe egress for all occupants outside the area of origin
- Property Protection: Prevent thermal damage
- Mission Continuity: Minimize smoke spread

Design Objectives:

- Life Safety: Maintain tenable conditions
- Property Protection: Prevent flashover
- Mission Continuity: Prevent fire from spreading outside the room of origin

11.11. Tenability Criteria

In order to ensure the building occupants remain safe, a tenability criterion is used to set a tolerable level of exposure during the egress of the building. Table 12 below outlines the limits used in the analysis for tenability at a height of 6-ft above the occupied floor levels.

Table 12. Tenability Limits

Performance Criteria	Tenability Limit	Source
Temperature	60°C	SFPE Handbook 4th Edition 2-129 Table 2-6.20
Visibility	4 m	SFPE Handbook 4th Edition Table 2-4.2 for Familiar Occupants
Radiant Heat Flux	2.5 kWm^{-2} or 375°C	SFPE Handbook 4th Edition 2-129 Table 2-6.20
Carbon Monoxide (CO)	30,000 ppm/min (1,000 ppm for 30 minutes)	NFPA 101

11.11.1. Temperature: <60℃ for >30 minutes

For a smoke layer 6-ft above the walking surface a temperature tenability limit of 60°C is used. The tenability limit of 60°C allows exposure for 30 minutes at that level without it having a life threatening effect on the egressing occupants (SFPE Handbook 4th Edition Table 2-6.20). Table 13 below, shows the tenability limits for heat.

Table 13. Tenability Limits for Heat

Table 2-6.20 ***Limiting Conditions for Tenability Caused by Heat***[108]

Mode of Heat Transfer	Intensity	Tolerance Time
Radiation	<2.5 kW·m^{-2}	>5 min
	2.5 kW·m^{-2}	30 s
	10 kW·m^{-2}	4 s
Convection	<60°C 100% saturated	>30 min
	100°C <10% H_2O*	12 min
	120°C <10% H_2O	7 min
	140°C <10% H_2O	4 min
	160°C <10% H_2O	2 min
	180°C <10% H_2O	1 min

*v/v

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11.11.2. Visibility: 4 Meters

The smoke layer should not descend before 6 feet above the walking surface. A visibility limit of 4 meters can also be employed for occupants that are familiar with their surroundings (SFPE Handbook 4th Edition Table 2-4.3). All occupants of the PF building have gone through training in order to be familiar with their surroundings. Table 14 below, shows the visibility limits.

Table 14. Tenability for Visibility – SFPE HB. Table 2-4.3

Table 2-4.3 ***Values of Visibility and/or Allowable Smoke Density for Fire Safe Escape Proposed by Fire Researchers***

Proposer	Visibility	Smoke Density (extinction coefficient)
Kawagoe[7]	20 m	0.1 1/m
Togawa[8]	—	0.4 1/m
Kingman[9]	4 ft (1.2 m)	—
Rasbash[10]	15 ft (4.5 m)	—
Los Angeles Fire Department[11]	45 ft (13.5 m)	—
Shern[12]	—	0.2 1/m
Rasbash[13]	10 m	0.2 1/m

11.11.3. Radiant Heat Flux: < 2.5 $\mathrm{kW/m^2}$

The hot smoke layer can produce a radiant heat flux to the occupants walking below it. This heat flux shall not exceed 2.5 $\mathrm{kW/m^2}$ in order to keep occupants from experiencing pain on exposed skin. In order to stay below this value the smoke layer temperature needs to stay below 375℃ (SFPE Handbook 4th Edition Figure 2-6.31) as shown in Figure 17 below.

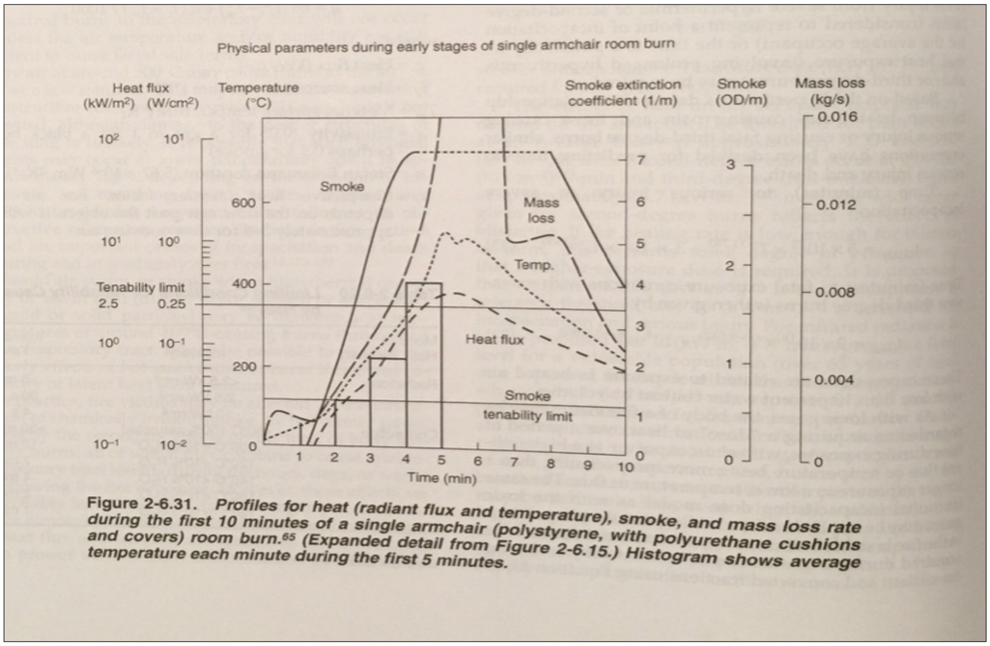


Figure 17. Heat Flux & Temperature from the SFPE HB. Figure 2-6.31

11.11.4. Carbon Monoxide: 1,000 ppm for 30 minutes

A person's ability to exit a building is impaired by a decrease in the amount of oxygen in the building along with the toxic effects that Carbon Monoxide has. NFPA 101 defines a tolerable amount of CO to be at 1,000 ppm for up to 30 minutes of exposure. This report follows LSC 5.2.2 Method 1 which describes a fractional effective dose (FED) calculation approach. FED addresses the effects of carbon monoxide, hydrogen cyanide, carbon dioxide, hydrogen chloride, hydrogen bromide, and anoxia. The LSC lists 0.8 as the non-lethal exposure level; however there is a need to distinguish FED levels between incapacitation and fatality. Incapacitation occurs at one-third to one-half of the lethal exposure. Thus, is a FED value of 0.8 were used for non-lethal exposure, a FED of 0.3 would be reasonable for a non-incapacitating exposure. For a building where an unusually large fraction of the occupants are especially vulnerable – for example occupants with asthma or other breathing-related issues – the FED value should be modified to lower levels than stated above. The Authority Having Jurisdiction (AHJ) must approve the acceptance threshold for the FED level. Purser also describes another method for estimating time to incapacitation in smoke atmospheres – taking into account interactions between toxic fire gases. This composition is dependent on the composition of the actual fire atmospheres, but for most practical situations, CO will be the most important toxic product. The most important interaction will bean increased rate of CO uptake due to hyperventilation caused by CO2. The fractional dose equation for asphyxiation would be:

Equation for asphyxiation would equal:

$$F_{IN} = [(FI_{CO} + F_{IC} + FI_{\mathrm{NO}x} + FLD_{irr}) *V\mathrm{CO2} + FED_{\mathrm{IO}} \text{ or } F_{IN} = FI_{CO2}$$

Where:

F_{IN} = Fraction of an incapacitating dose of all asphyxiant gases

$FI_{CO=}$ Fraction of an incapacitating dose of CO
$FI_{CN=}$ Fraction of an incapacitating dose of HCN
$F_{INO}x$= Fraction of an incapacitating dose of NO + NO2
FLD_{irr} = Fraction of an irritant dose contributing to hypoxia
VCO_2= Multiplication factor for CO2-induced hyperventilation
FED_{10} = Fraction of incapacitating dose of low-oxygen hypoxia

F_{ICO2} = Fraction of an incapacitating dose of CO2

An F_{IN} = 1 is appropriate for incapacitating, and death is predicted at approximately two to three times the incapacitating dose. A complete tenability analysis can be performed for a specific fire scenario with data for release rates of smoke, CO and CO2.

11.11.5. Flashover

Room flashover is associated with fire and smoke spread outside the room of origin. When flashover occurs, the room integrity is compromised and the fire and smoke will no longer be contained to the room of origin. If smoke were to spread from a room to the corridor, major egress paths could be compromised. Also, smoke spread could impact the functionality of highly sensitive test equipment in various laboratories. SFPE HB Sect 3-6 describes how research conducted by Thomas [3] indicates the onset of flashover is typically represented by an upper gas layer of 500-600℃. The conservative upper gas layer temperature of 500℃ will be used for flashover criterion.

11.11.6. Performance Criteria Summary

Table 15 below, summarizes the aforementioned fire protection goals, design objectives and their respective performance criteria.

Table 15. Summary of Performance Goals, Objectives, and Criteria

Fire Protection Goal	Stakeholder Objective	Design Objective	Performance Criteria
Minimize fire related injuries	Allow safe egress for all occupants outfit the room of origin	Maintain tenable conditions	Visibility > 4 m
			Smoke Layer Height > 1.83m
			CO < 1000 ppm
			Room Temperature < 60°C
Minimize fire related damage to the buildings and its contents	Prevent thermal damage	Prevent Flashover	Upper Layer Temperature < 500°C
Minimize undue loss of operation	Minimize smoke spread	Prevent fire and smoke from spreading outside the room of origin	Upper Layer Temperature < 500°C

11.12. Egress Analysis

11.12.1. Egress Analysis Introduction

This section will provide the information necessary to calculate the total egress time. The chosen fire scenarios in the preceding sections of this report contain their own egress analyses for their respective occupant loads and exiting layouts. An egress analysis is used to calculate the RSET. The RSET is how long it will take for the occupants to exit the building. The RSET includes detection time, alarm time, pre-movement time, and travel time. The RSET is then compared to the ASET in order to determine if occupants have enough time to safely exit the facility or area. The ASET is calculated by modeling fire scenarios and determining when they exceed the performance criteria. The ASET must be greater than the RSET in order for a safe egress to occur. If the ASET is less than the RSET, the building fails the fire scenario and corrective actions will be recommended to increase the ASET. Figure 18 below, taken from NFPA HB Fig. 3.11.4, portrays the RSET vs. ASET calculations.

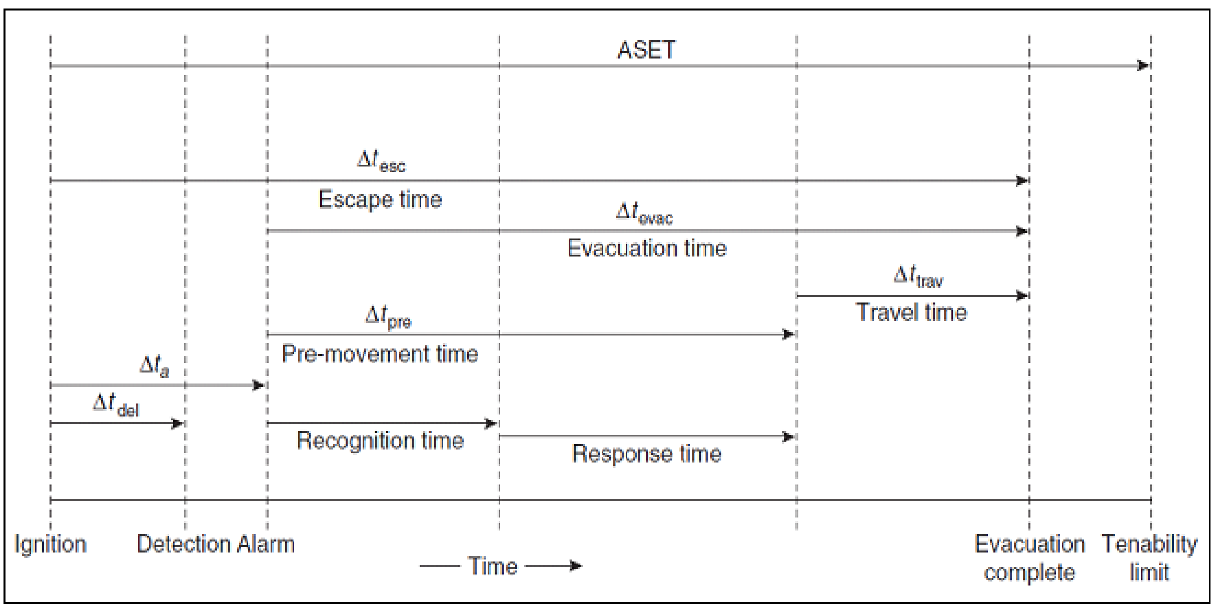


Figure 18–ASET vs. RSET

11.12.2. Egress Calculation Methods

The following steps will be used to calculate the egress time for each chosen fire scenario:

Determine the occupant load for the room or building (P)

Determine the number of available exit doors from the room or building (D)
Determine effective width of each door (W_e)
Determine the specific flow of each door (F_s)
Calculate the flow capacity of each door (F_c)
Calculate the time of passage through all available doors (t_p)
Determine the pre-movement time ($t_{p\text{-}e}$)
Calculate the detection time (t_d)
Calculate the exit time (t_e)

11.12.3. Egress Assumptions

All occupants start egress at the same time. Queuing will occur at the doors to the outside therefore the specific flow; F_S will be the maximum specific flow, $F_{SM.}$. The population will use all facilities in the optimum balance. None of the private exits will be considered for the chosen scenarios.

11.12.4. Pre-movement Time

Pre-movement time is the time it takes an occupant to perform activities prior to leaving the building. PF occupants are likely to increase their pre-movement time by engaging in the following activities:

- Finding keys, jackets or purses
- Putting on gloves, hats or heavy jackets (in the winter)
- Taking off safety glasses or lab coats
- Shutting down experiments and/or putting away chemicals
- Locking the computers (a security requirement)
- Looking for a co-worker to egress with
- Interns and new employees looking for mentors for guidance on where to go

The pre-movement time was determined from Table 4.2.1 of the NFPA Handbook (Table 16 below). The mid-rise office building occupancies most closely resemble the PF in occupant characteristics. The lower median value of 0.6-min. (36-seconds) was chosen due to the nature of the occupants and the layout of the building.

Table 16. Delay Times – NFPA Handbook

TABLE 4.2.1 Delay Times (Minutes) Derived from Actual Fires and Evacuation Exercises Reported in the Referenced Literature

Event Description	*N*	*Min*	*1st Q*	*Median*	*3rd Q*	*Max*	*Mean*	*Factors*
High-rise hotel[14]	536	0	3.3	60.0	130.9	290.0	NA*	MGM Grand Hotel fire, no alarm notification, grouped data from questionnaires
High-rise hotel[15]	47	0	2.0	5.0	17.5	120.0	NA	Westchase Hilton Hotel fire, no alarm in early stages, grouped data from questionnaires
High-rise office building[16]	85	0	2.0	5.0	10.0	245.0	11.3	World Trade Center explosion and fire, no alarm notification (building closer to explosion)
High-rise office building[16]	46	0	4.5	10.0	31.5	185.0	28.4	World Trade Center explosion and fire, no alarm notification (building further from blast)
High-rise office building[17]	107	1.0	1.0	1.0	1.0	~6.0	NA	Fire incident, no alarms, data from interviews with occupants of four floors of building (11 interviewees were trapped)
High-rise office building[18]	12	0.5	NA	1.0	NA	2.3	1.2	Unannounced drill on three floors; data for first person to reach each of four stairwell doors to wait for voice instruction; trained staff; data from video recordings
Mid-rise office building[19]	92	0	0.4	$\boxed{0.6}$	0.8	<4.0	0.6	Unannounced drill, good alarm performance; fire wardens; warm day
Mid-rise office building[19]	161	0	0.5	0.9	1.4	<5.0	1.1	Unannounced drill, good alarm performance; fire wardens; cool day

11.12.5. RSET Detection and Notification Times (t_d) – All Scenarios

The time to detection and notification are combined into the t_d value as shown below:

Scenarios 1A and 1B: t_d = 31s (1st smoke detector activation)

The above detection time was determined through FDS simulations.

11.12.6. RSET Egress Travel/Evacuation Times (t_e) – All Scenarios

The egress (travel) time of occupants assuming a completely full occupant load using a Pathfinder ® model (Reference Appendix N) utilizing imported drawings of the floor layout. Both the Steering and SFPE Models were recorded, but only the travel time utilizing the Steering Model will be used due to its more realistic nature. The travel times for both egress models are as follows:

Fire Scenarios 1A and 1B:

Steering Model: 109 seconds (this value is used in the formula for Section 11.12.7 below)

11.12.7. RSET Pathfinder Calculations – All Scenarios

Pathfinder RSET – Steering Model (1st Floor): ***109 s (1.82 min.) for 412 occupants***

- $RSET = t_d + t_{p-e} + t_e$

t_d = 31 s *(Smoke detector activation plus 2 second lag time)*

t_{p-e} = 36 s *(Pre-Movement time previously stated)*

t_e = 109 s *(movement time to exits from previous section)*

$$RSET\ (1st\ Detector\ Activation) = 31s + 36s + 109s = \mathbf{176\ s}\ (\boldsymbol{approx.\ 3\ min})$$

Where:

t_d = Time from fire ignition to detection (includes t_n)

t_{p-e}= Pre-evacuation (aka Pre-movement time)

t_e = Time form start of purposive evacuation movement until safety is reached

As noted above, the Pathfinder ® model predicted a total building movement time of 109 seconds. The Pathfinder movement time value compares nicely with the hydraulic model value from Section 4.7.4 of this report which estimated a movement time of 106 seconds. Appendix N provides information and screen-shots from the Pathfinder model used for the PF.

11.13. Fire Scenarios

11.13.1. Fire Scenario 1A – Kitchen Appliance Fire (Sprinklers Disabled)

The first design fire originates from the ignition of microwave oven. It is analyzed due to its more frequent nature than the other scenarios. To complicate this scenario, the sprinklers are assumed to not work based off Design Scenario 8 of the LSC: an ordinary combustible fire where the active fire protection is ineffective. The fire alarm system is still assumed to work and will notify occupants upon activation.

11.13.2. Room Characteristics

This kitchen appliance fire will start in a small kitchen (aka, kitchenette) on the first floor of the building. This area is normally unoccupied, however occupants can use the area during the day to heat things up, make coffee, clean dishes, etc. The room does not have a door and opens to the corridor, which occupants could use for part of their egress from the office area or conference room. The kitchenette room itself is 8’H x 11.5’L x 5.2’W and the microwave oven sits on top of a wood table with a coffee maker adjacent to it. The exact room location on the first floor is shown shaded in blue in Figure 19 below.

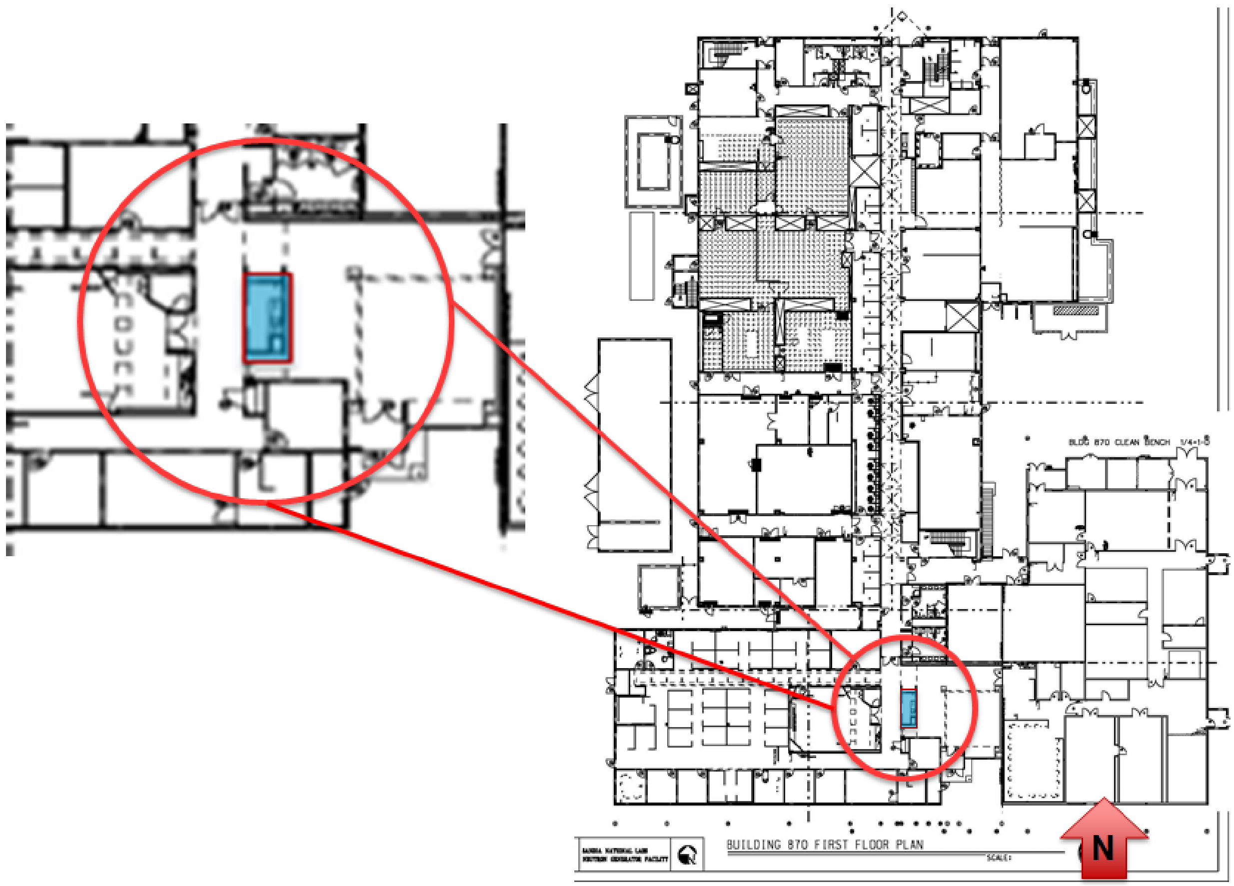


Figure 19 – First Floor Kitchenette Location

There is a photoelectric smoke detector located outside the kitchenette that will activate at 3.28% obscuration. For the first fire scenario, it is assumed the sprinklers are impaired and do not activate. There are fire extinguishers nearby, but for the purpose of this scenario, it is assumed that they are not utilized. The hallway and opening to the kitchenette are shown in Figure 20 below.

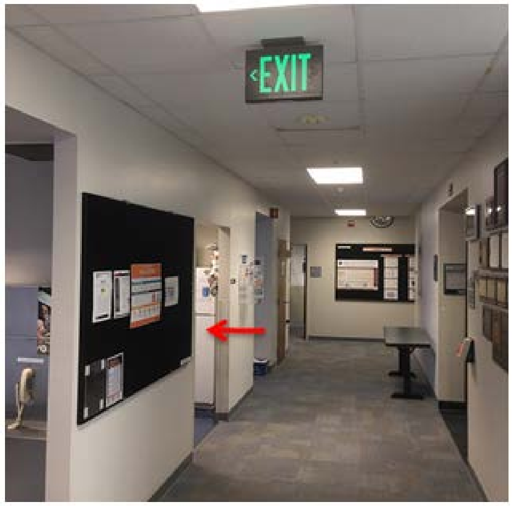


Figure 20 – First Floor Hallway and Kitchenette Location (arrow)

11.13.3. Occupant Characteristics

A complete occupancy load analysis is provided earlier in this report. Occupants are not in this small room every minute of every day and it remains for the most part unoccupied. PF occupants are all over sixteen years old, capable of egressing in a reasonable time and familiar with the building. Based on the aforementioned information, pre-movement times were determined to be 36 seconds. The movement time for this scenario is based off of testing done on walking speed in smoke. The maximum walking speed time is approximately 1.2 m/s maximum with a small extinction coefficient. The furthest distance from the exit is 40.2 ft meters. Assuming that there are not enough occupants to queue in individual rooms and the maximum time is spent walking to the exit, the movement time would then equal 34 seconds (1.2 m/s / 40.2 m). The pre-movement time and the movement time will be added to the time to alarm time in order to determine the required safe egress time for this scenario. The first smoke detector activation alarm time was found to be 29 seconds and 2 seconds was added to that for system lag time. The Pathfinder RSET was previously determined to be 176 seconds, so this worst-case value will be used for the 1st floor RSET requirement. All of the first floor FDS model smoke detector activation times are shown in Table 17 below. The smoke detector labeled “SD” in the table is located in the hallway directly outside of the kitchenette.

Table 17. FDS Smoke Detector Activation Times

DEVICE Activation Times		
1	SD	28.6 S
2	SD01	86.3 S
3	SD02	77.3 S
4	SD03	78.0 S
5	SD04	78.1 S
6	SD05	135.9 S
7	SD06	109.6 S
8	SD07	105.7 S
9	SD08	129.5 S
10	SD09	138.0 S

11.13.4. Fire Characteristics

Heat release rates for wood table and coffee maker fires are known, but those for the primary ignition source such as the microwave are not, so assumptions had to be made. The first assumption is that the peak heat release rate is equal to 250kW. This number is intended to be conservative. For example, a 28" CRT television has a HRR of about 275kW [4] and is made of similar materials (plastic, electronic components, etc.) as a TV, therefore the HRR of 250kW for the microwave is conservative. For the coffee maker and microwave oven, the fire is assumed to be a t^2 fire with a medium growth, fast decay rate, and well ventilated. The wood table fire has a fast growth rate and slow decay. All fire scenarios were run for the full 600 seconds (10-min).

As shown in Figures 21 and 22 below, for Scenario 1A, the temperature does not rise above 60°C @ 1.83m (6-ft) in the means of egress or in the room so flashover (500°C) does not occur.

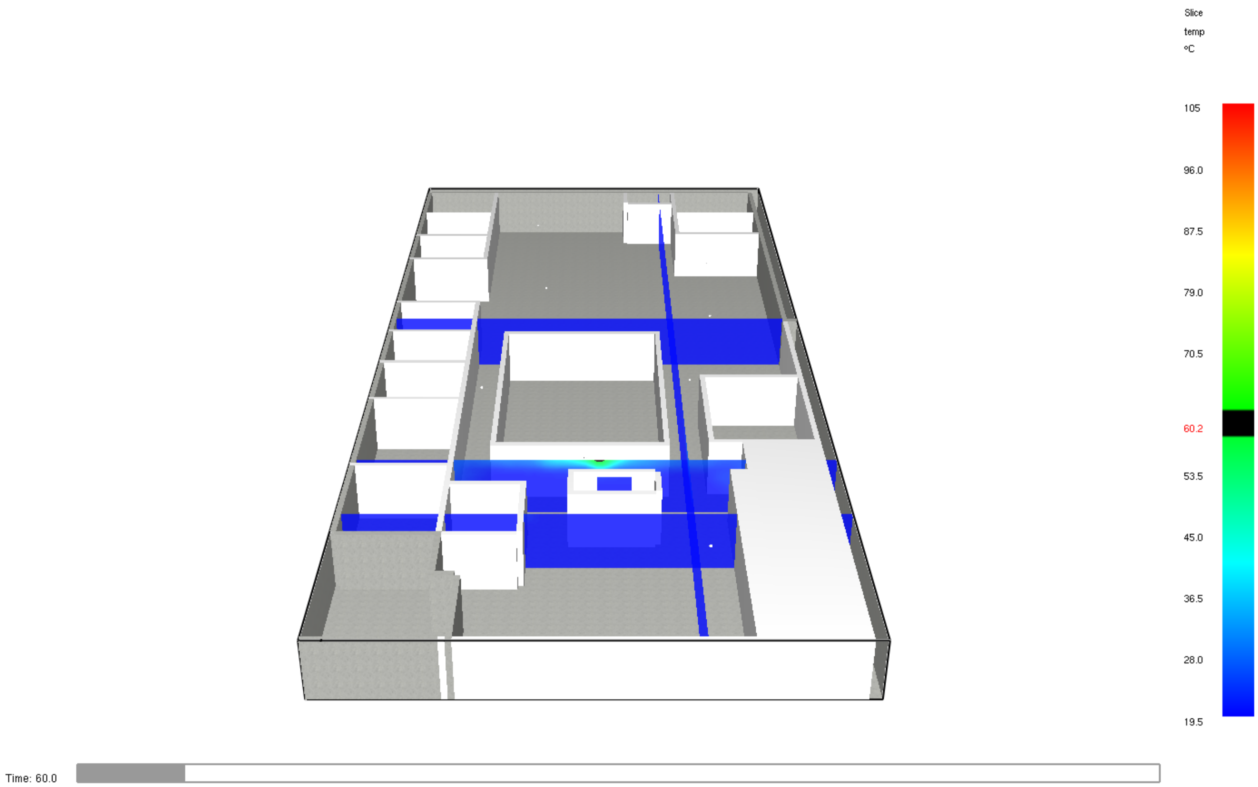


Figure 21 – Fire Scenario 1A: FDS Temperature @60s

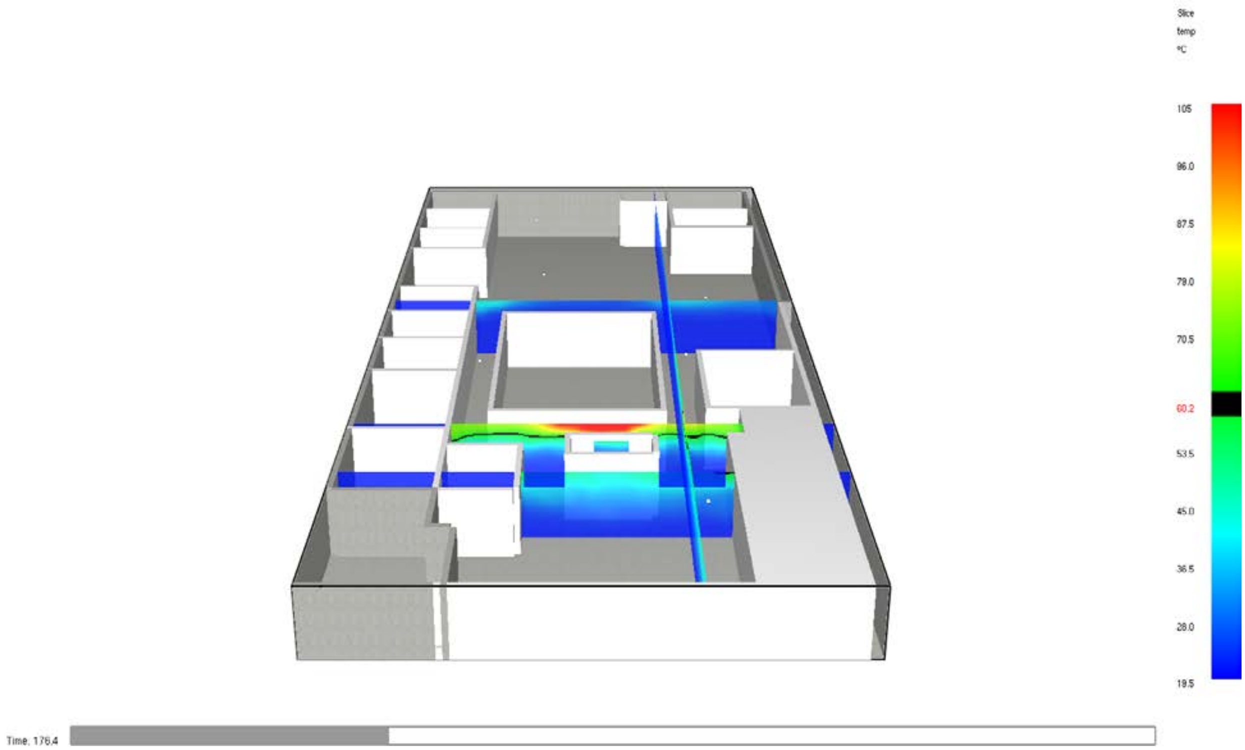


Figure 22 – Fire Scenario 1A: FDS Temperature @176s (RSET)

As shown in Figures 23, 24, and 25 below, the visibility falls below 4 m in the means of egress at around 66 seconds (this sets the ASET) in the corridor leading to the exit. All visibility is lost at 176 seconds (RSET).

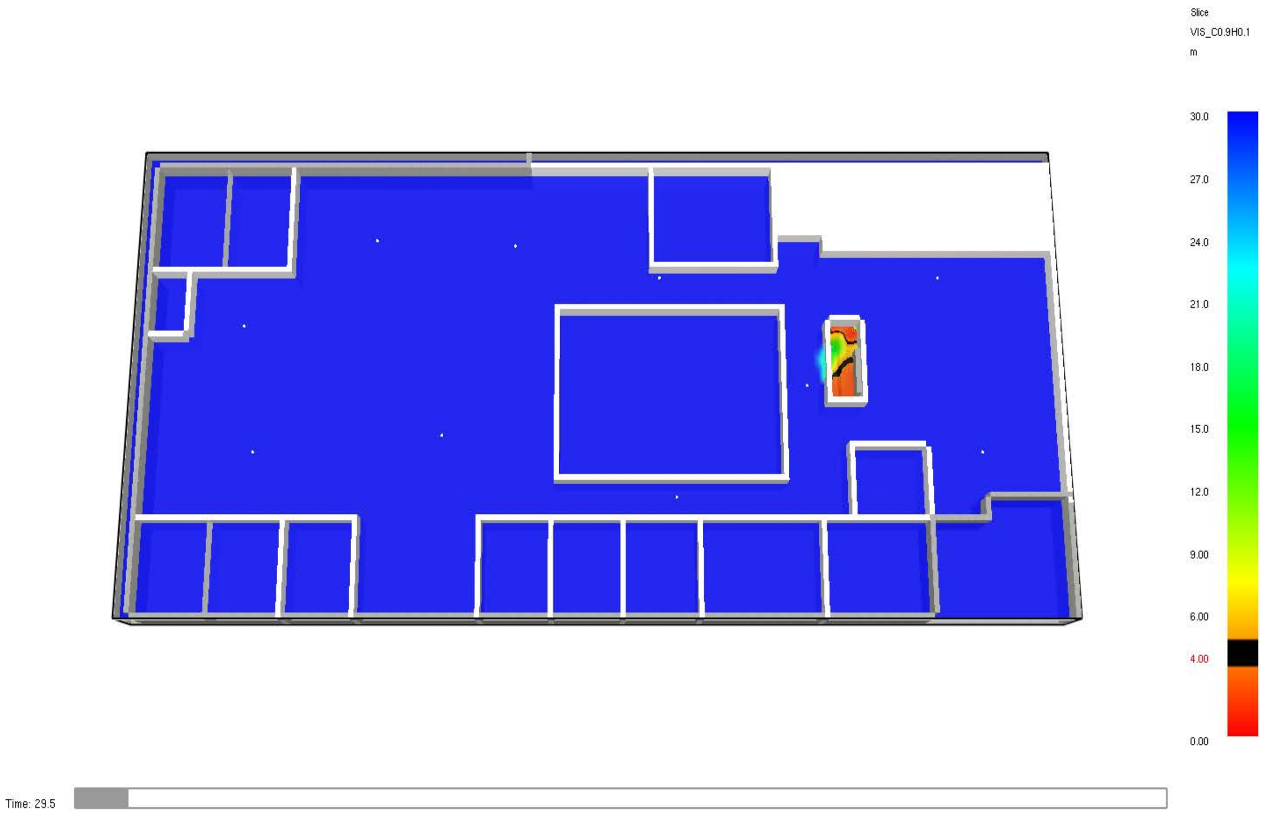


Figure 23 – Fire Scenario 1A: FDS Visibility @ 31s

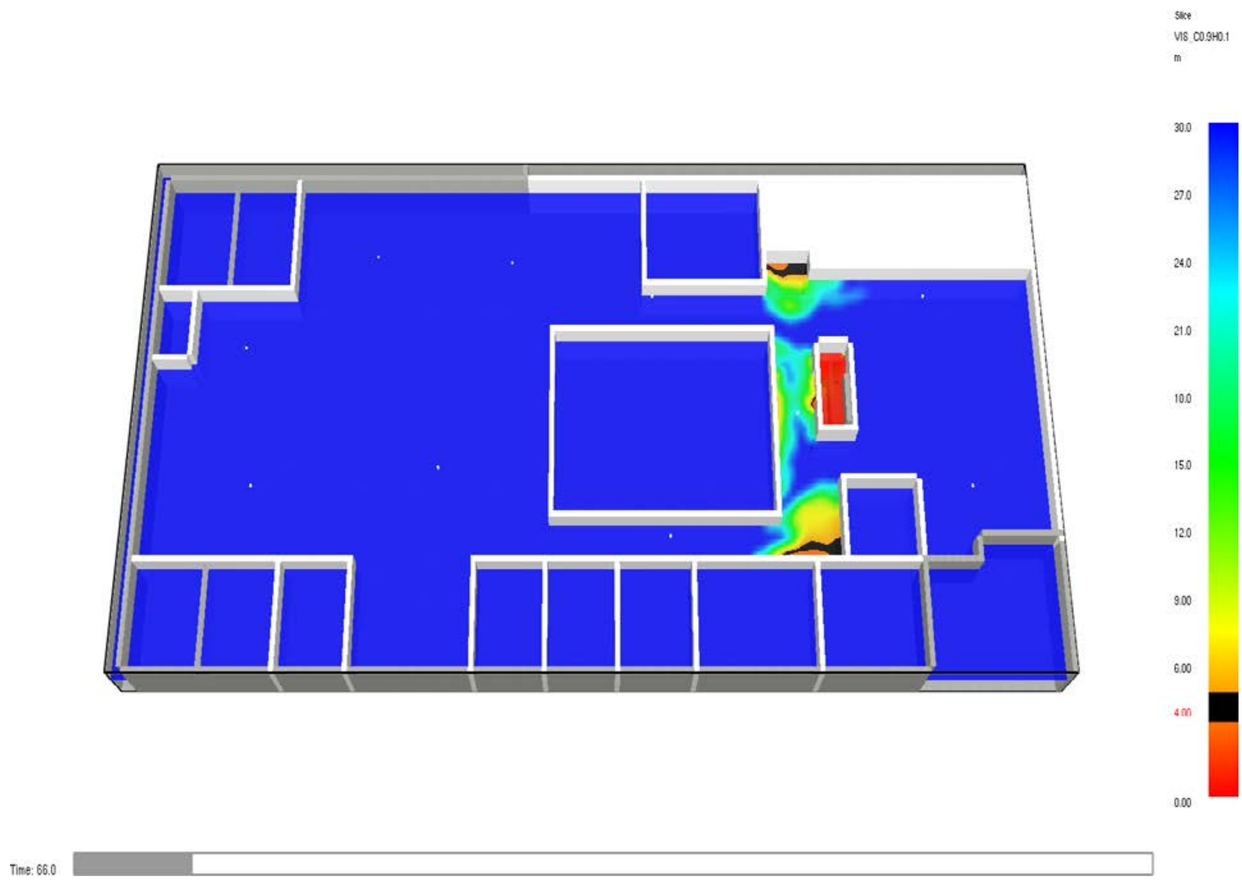


Figure 24 – Fire Scenario 1A: FDS Visibility @ 66s (ASET)

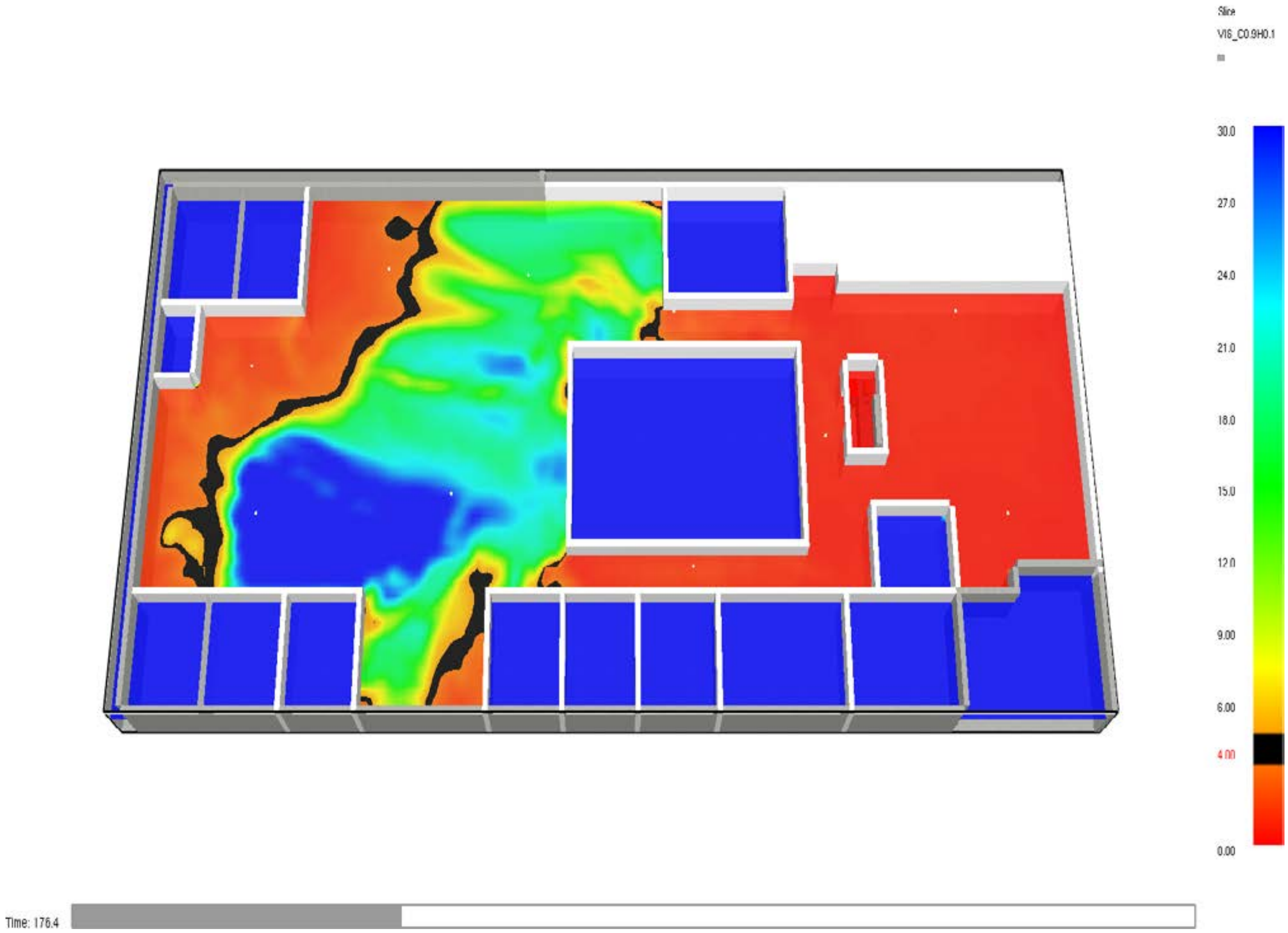


Figure 25 – Fire Scenario 1A: FDS Visibility @ 176s (RSET)

The smoke Layer Height > 6ft (1.83m)-Fails at 45 seconds as shown in Figure 26 below.

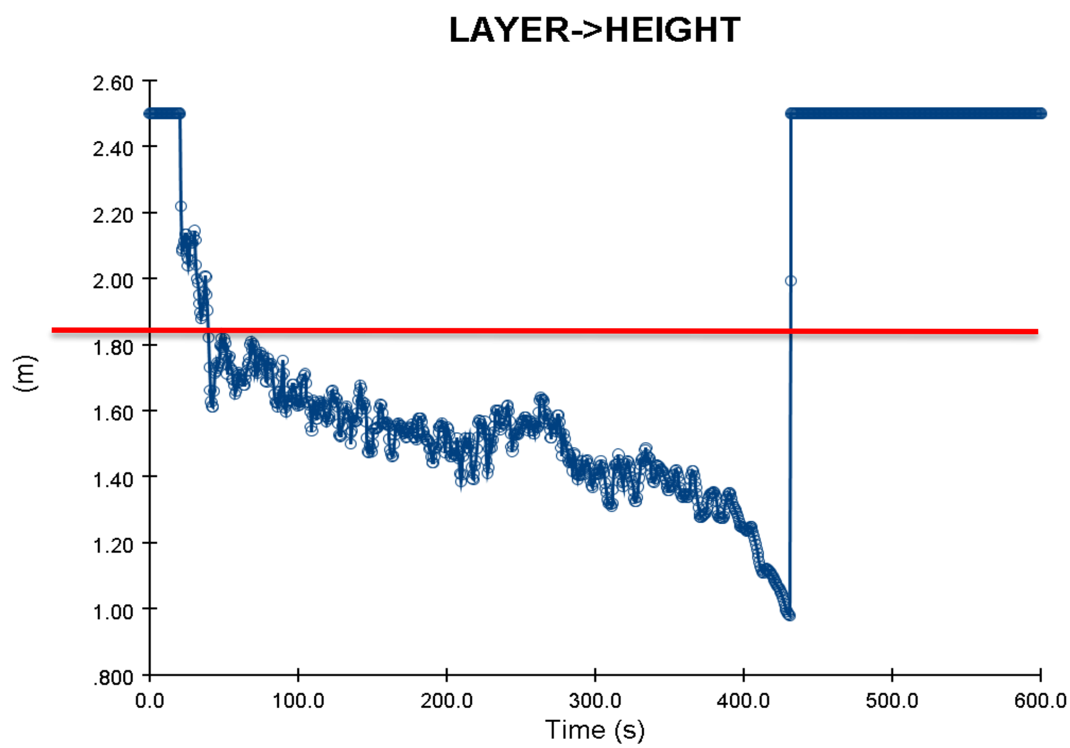


Figure 26 – Fire Scenario 1A: FDS Fire Smoke Layer Height

As shown in Figures 27 and 28 below, the Carbon Monoxide (CO) production is less than our tenability criteria of 1000 ppm, so it passes. The maximum that it reaches is 300 ppm on the scale.

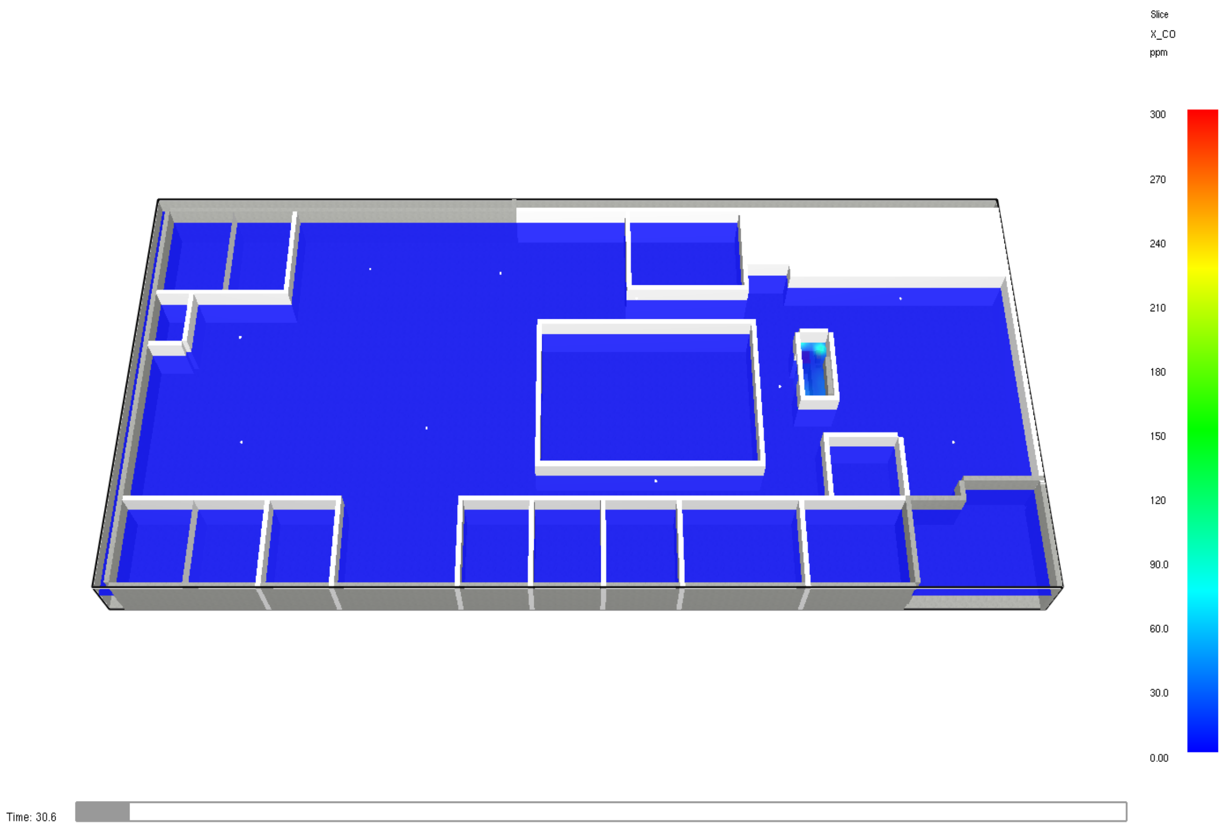


Figure 27 – Fire Scenario 1A: FDS CO @ 31s

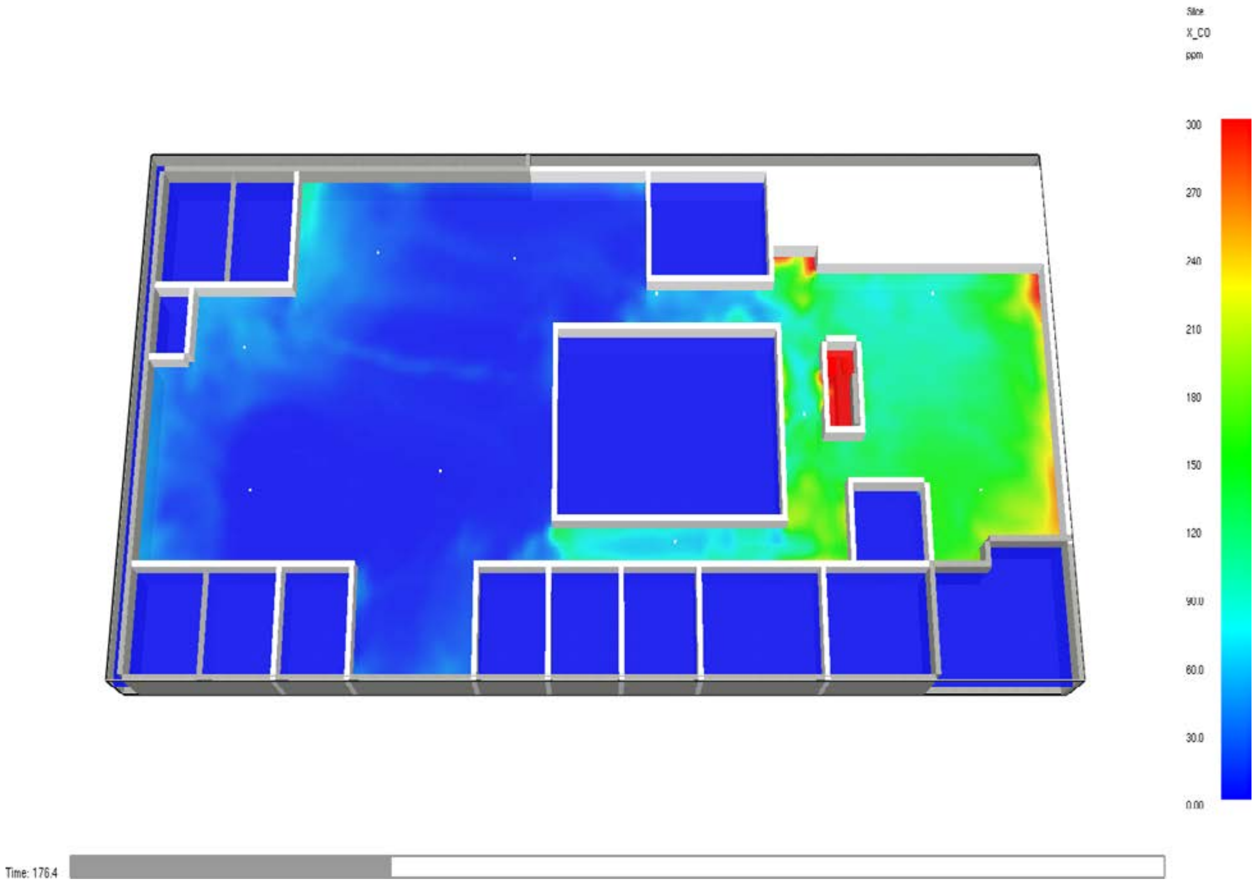


Figure 28 – Fire Scenario 1A: FDS CO @ 176s (RSET)

The smoke migration is shown in Figures 29 and 30 below.

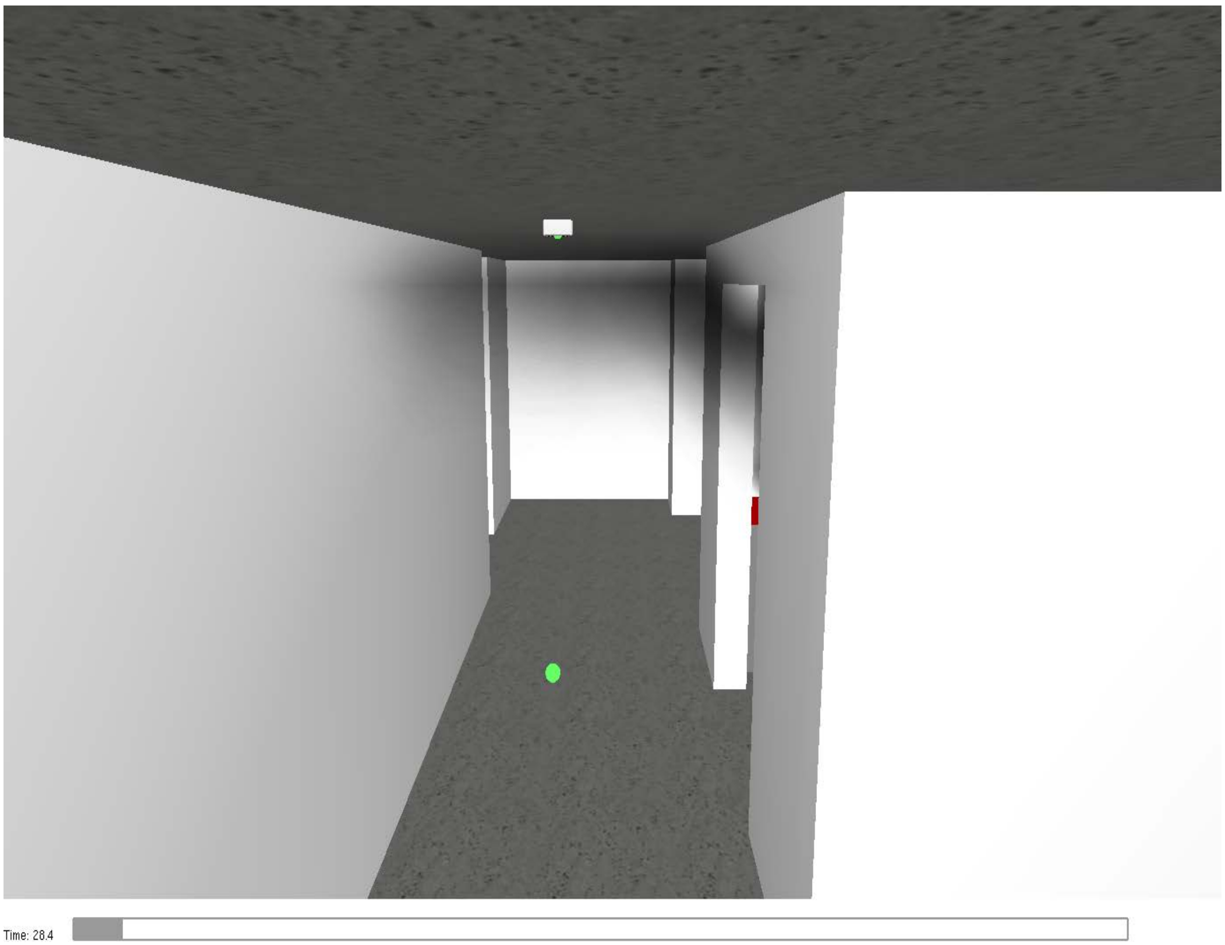


Figure 29 – Fire Scenario 1A: Corridor Smoke Progression Viewpoints @ 29s

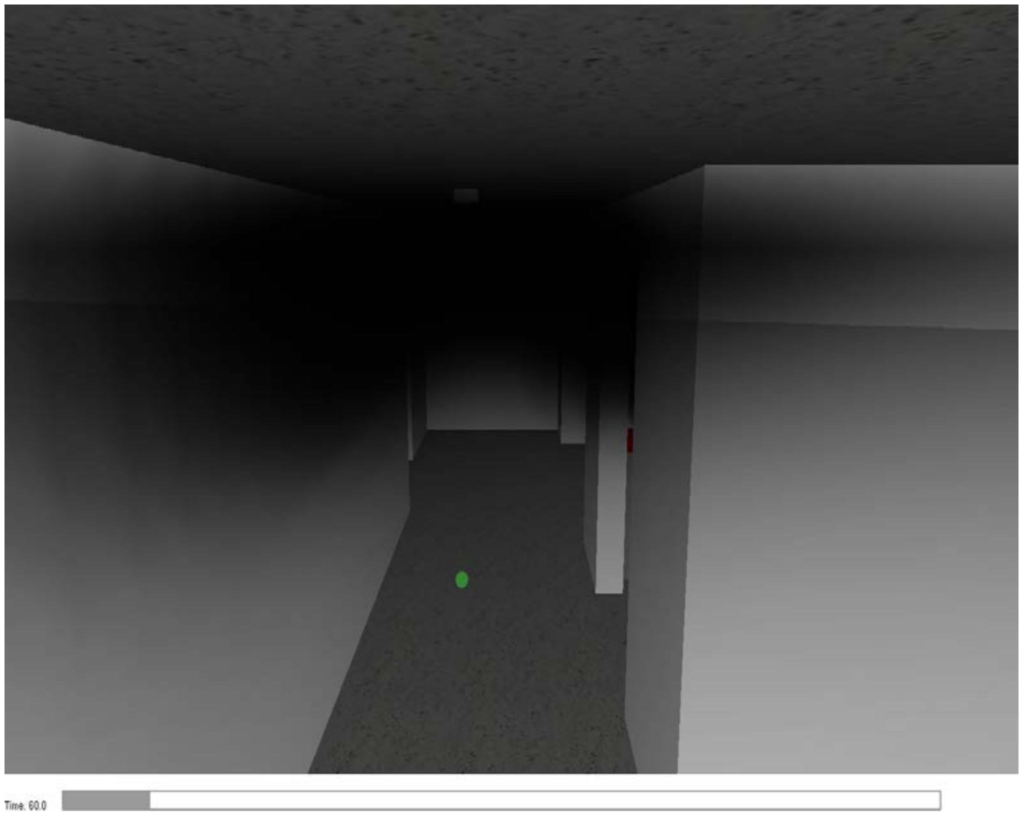


Figure 30 – Fire Scenario 1A: Corridor Smoke Progression Viewpoints @60s

A results table for Scenario 1A is shown in Figure 31 below.

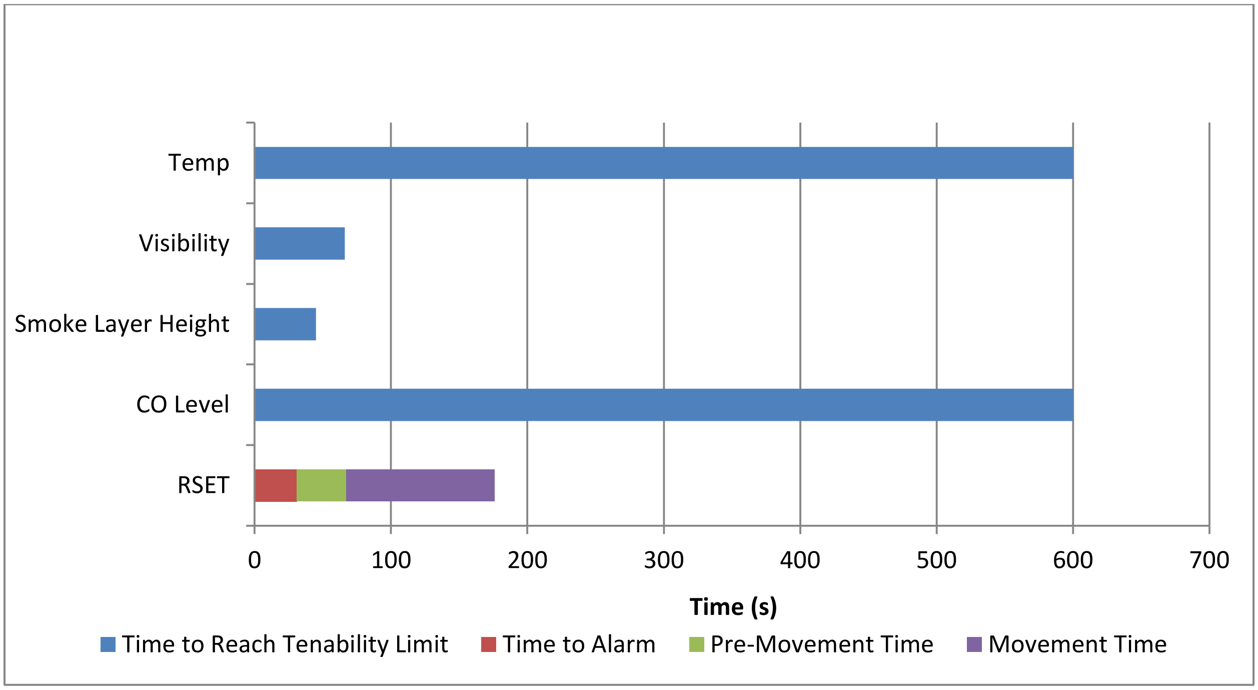


Figure 31 – Fire Scenario 1A: RSET vs. ASET Analysis

In summary, Scenario 1A fails the visibility and smoke layer height tenability requirements, however it passes the CO and temperature criterion so a percentage of the occupants could potentially exit the building without being overcome with the effects of heat or smoke. It is important to note that proper inspection, testing and maintenance should be done on all detection and notification devices and on the sprinkler system to ensure that everything will operate correctly in the event of a fire emergency.

11.13.5. Fire Scenario 1B – Kitchen Appliance Fire (Sprinklers Active)

The design fire is the same as Fire Scenario 1A, however the sprinklers are assumed to be operational based off Design Fire Scenario 1 of the LSC: An ordinary combustible fire where the active sprinkler system is effective in cooling the fire. The fire alarm system is assumed to work and will notify occupants upon activation.

As shown in Figures 32 and 33 below, for Scenario 1B, the temperature does not rise above 60°C @ 1.83m (6-ft) in the means of egress or in the room so flashover (500°C) does not occur.

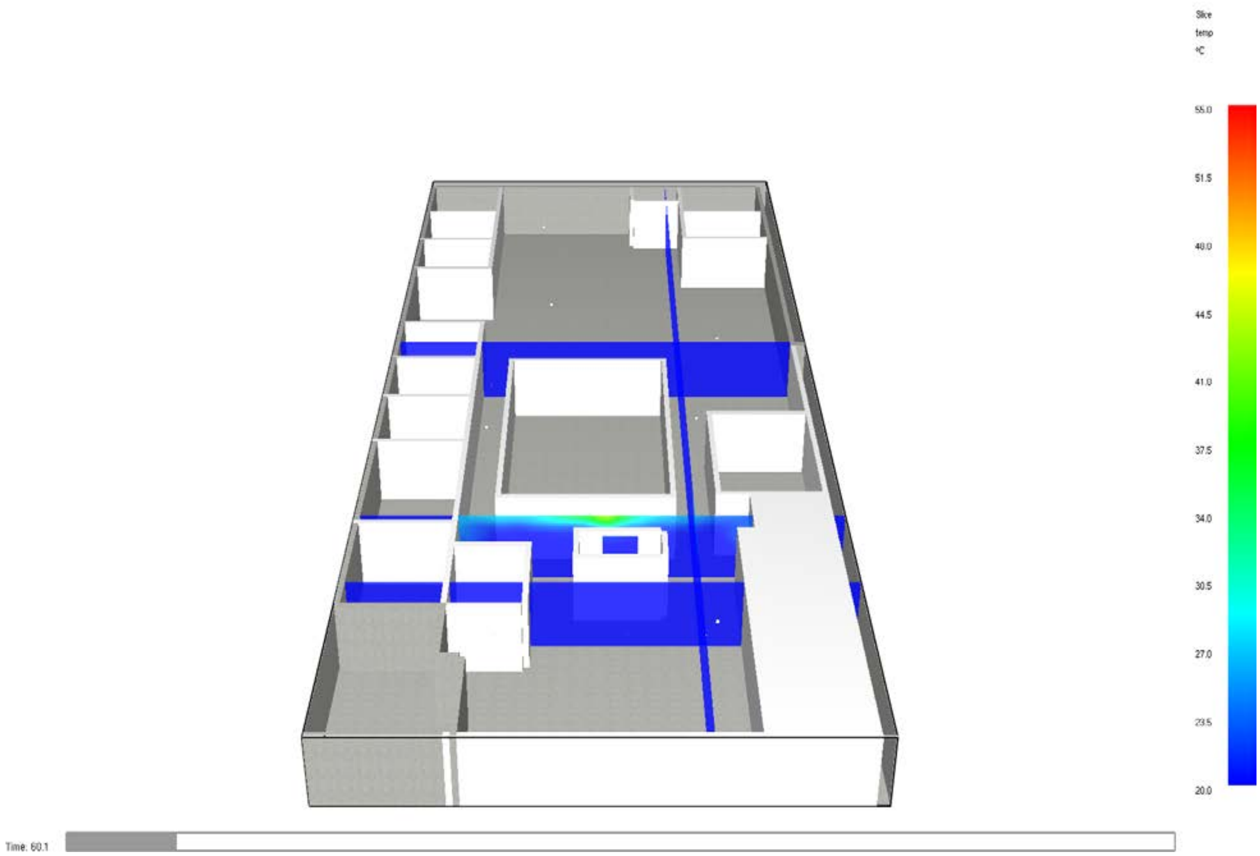


Figure 32 – Fire Scenario 1B: FDS Temperature @60s

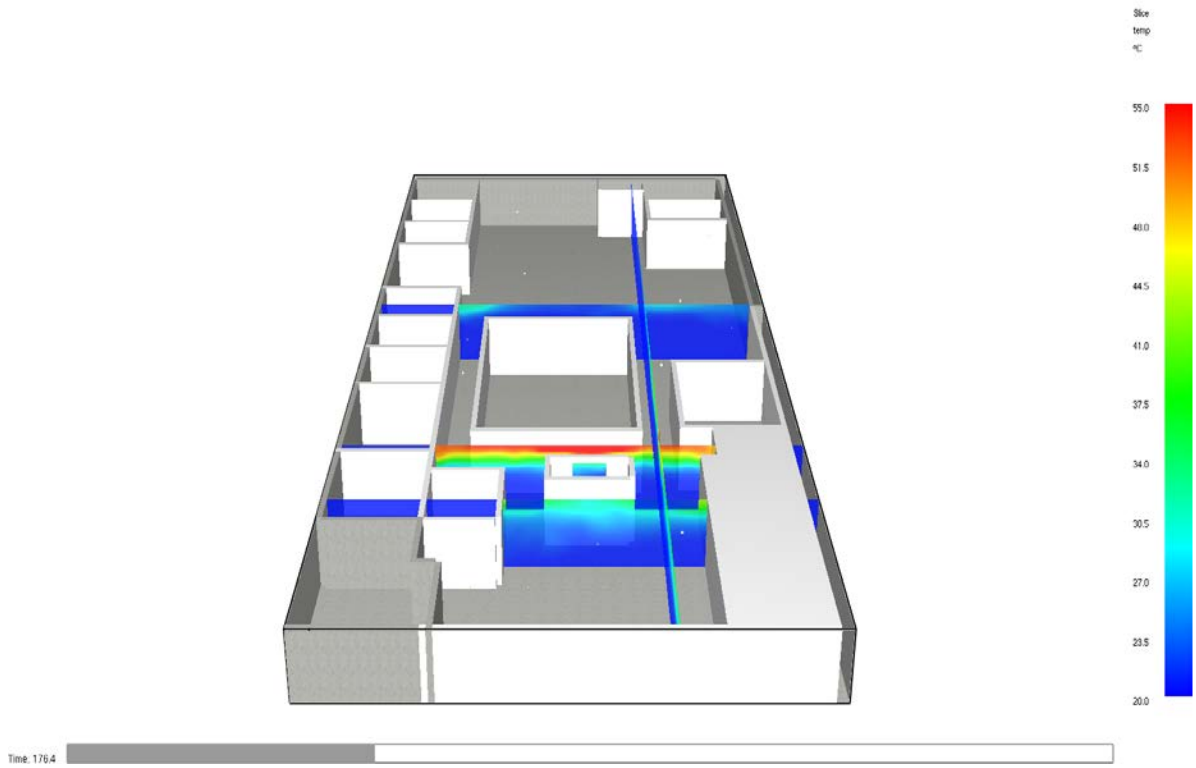


Figure 33 – Fire Scenario 1B: FDS Temperature @ 176s (RSET)

As shown in Figures 34, 35, and 36 below, the visibility falls below 4 m in the means of egress at around 128 seconds (this sets the ASET) in the corridor leading to the exit. All visibility is lost at 176 seconds (RSET).

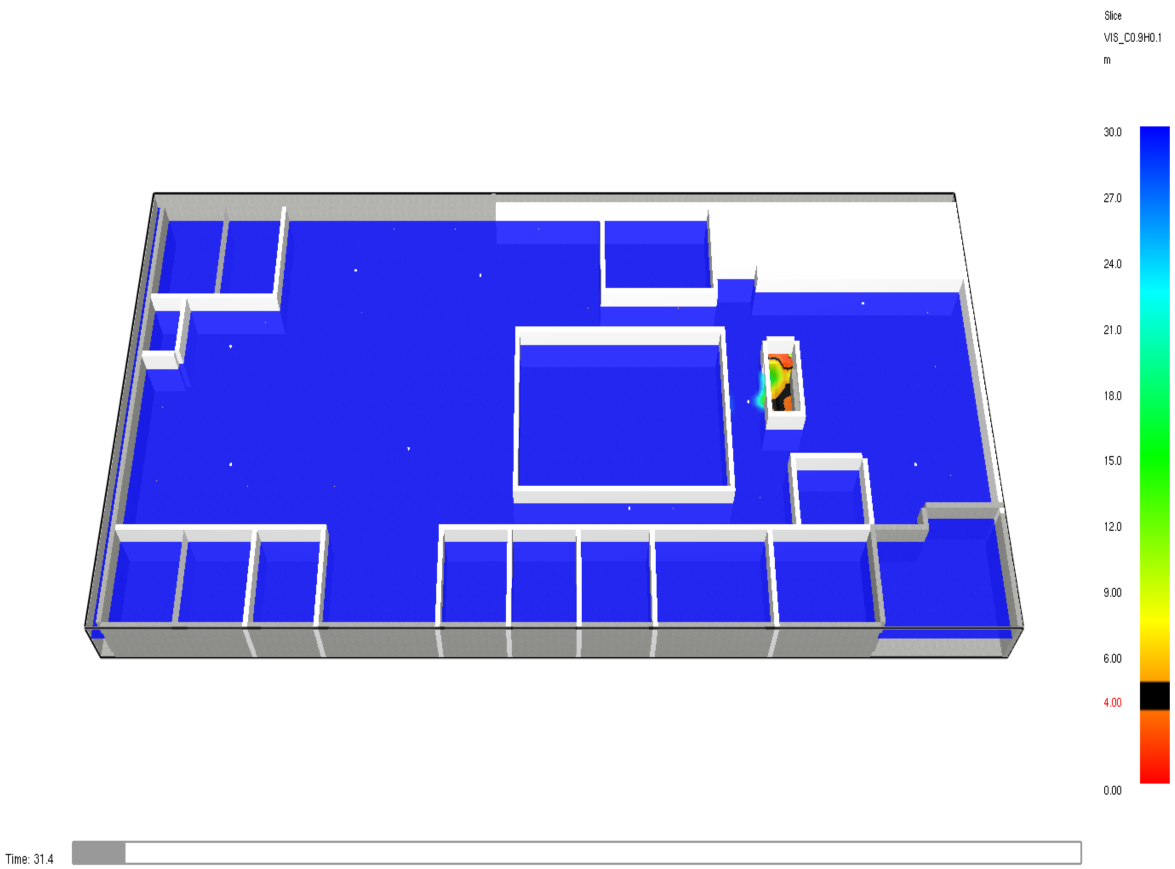


Figure 34 – Fire Scenario 1B: FDS Visibility @ 31s

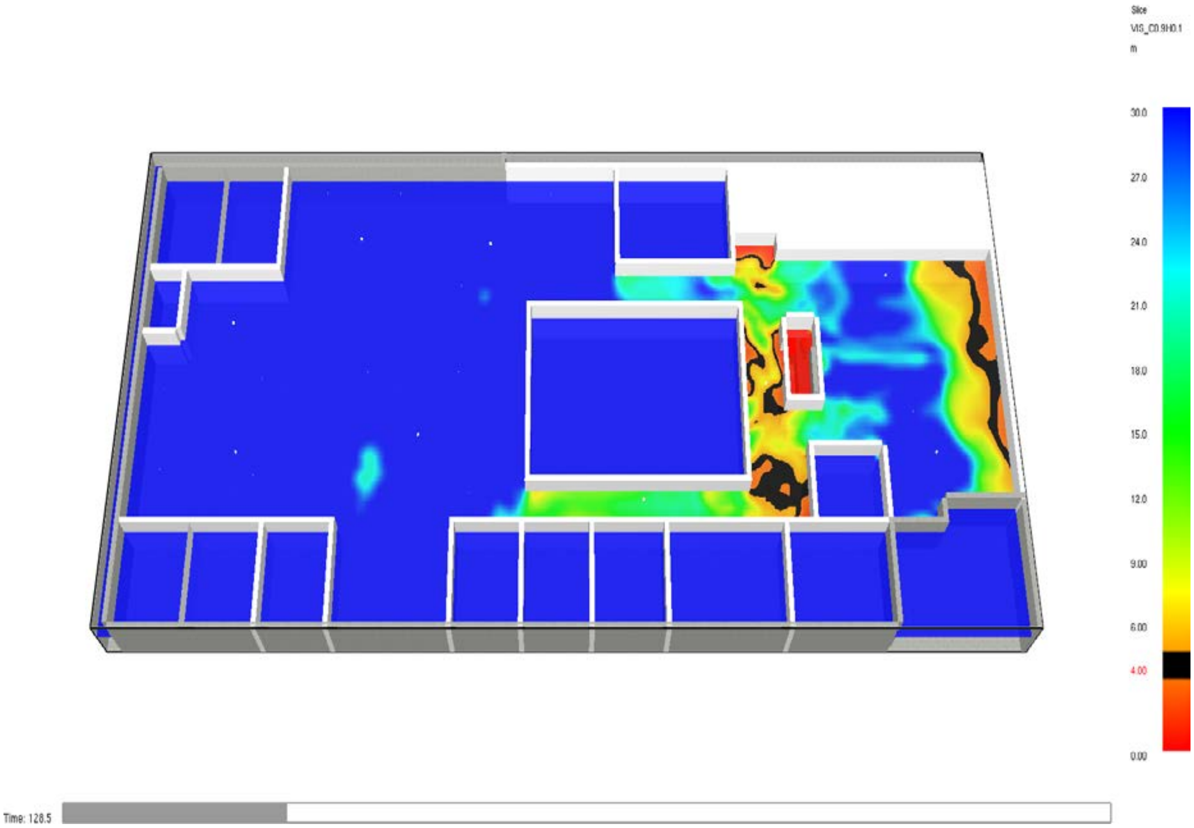


Figure 35 – Fire Scenario 1B: FDS Visibility @ 128s (ASET)

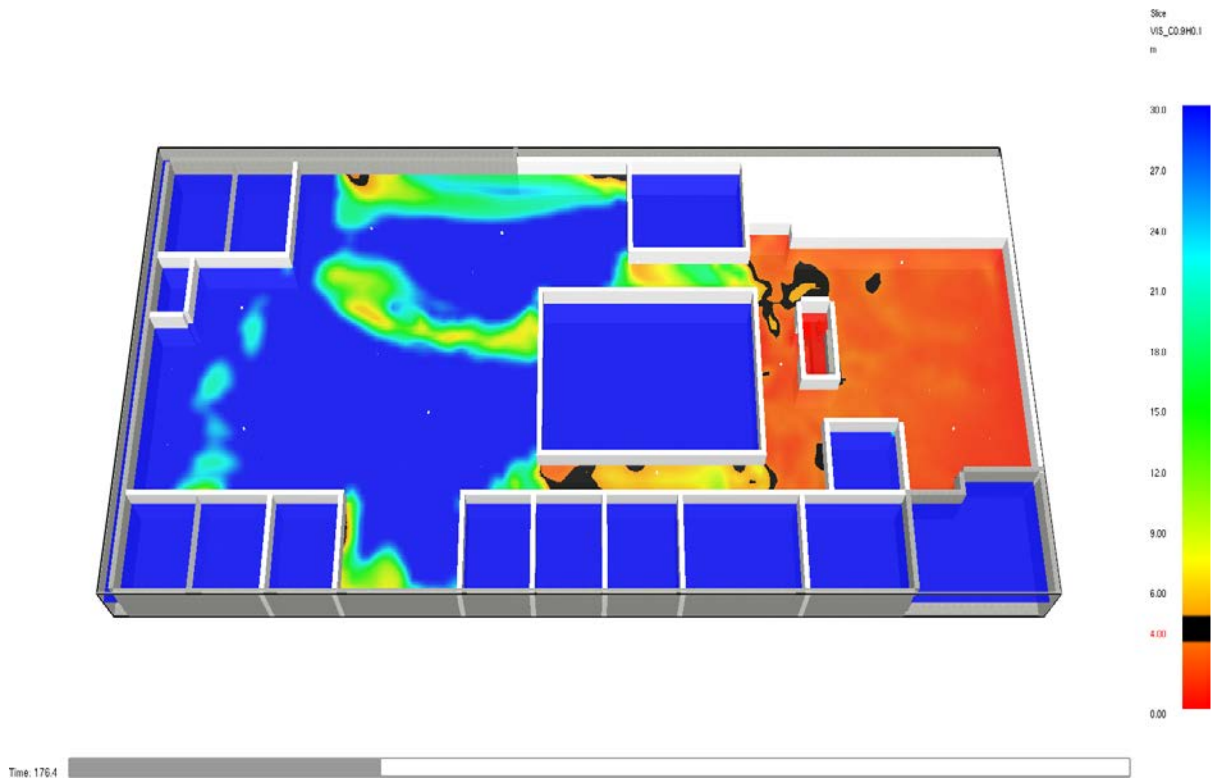


Figure 36 – Fire Scenario 1B: FDS Visibility @ 176s (RSET)

The smoke Layer Height > 6ft (1.83m)-Fails at 150 seconds as shown in Figure 37 below.

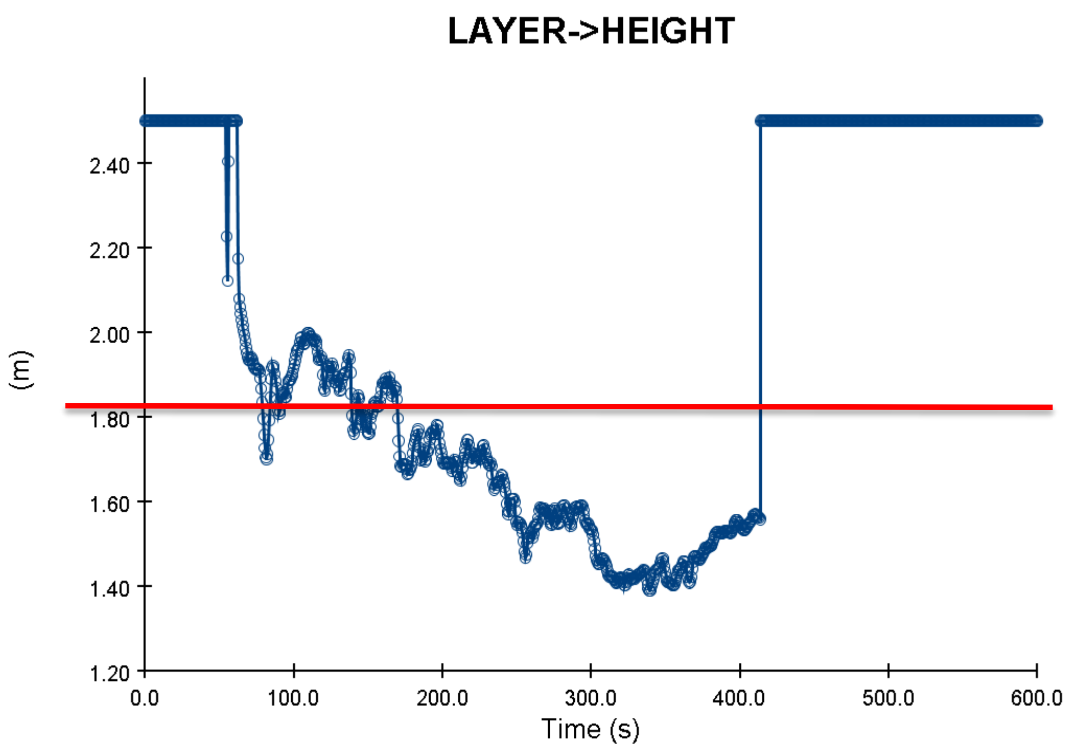


Figure 37 – Fire Scenario 1B: FDS Fire Smoke Layer Height

As shown in Figures 38 and 39 below, the Carbon Monoxide (CO) production is less than our tenability criteria of 1000 ppm, so it passes. The maximum that it reaches is 95 ppm.

Figure 38 – Fire Scenario 1B: FDS CO @ 31s

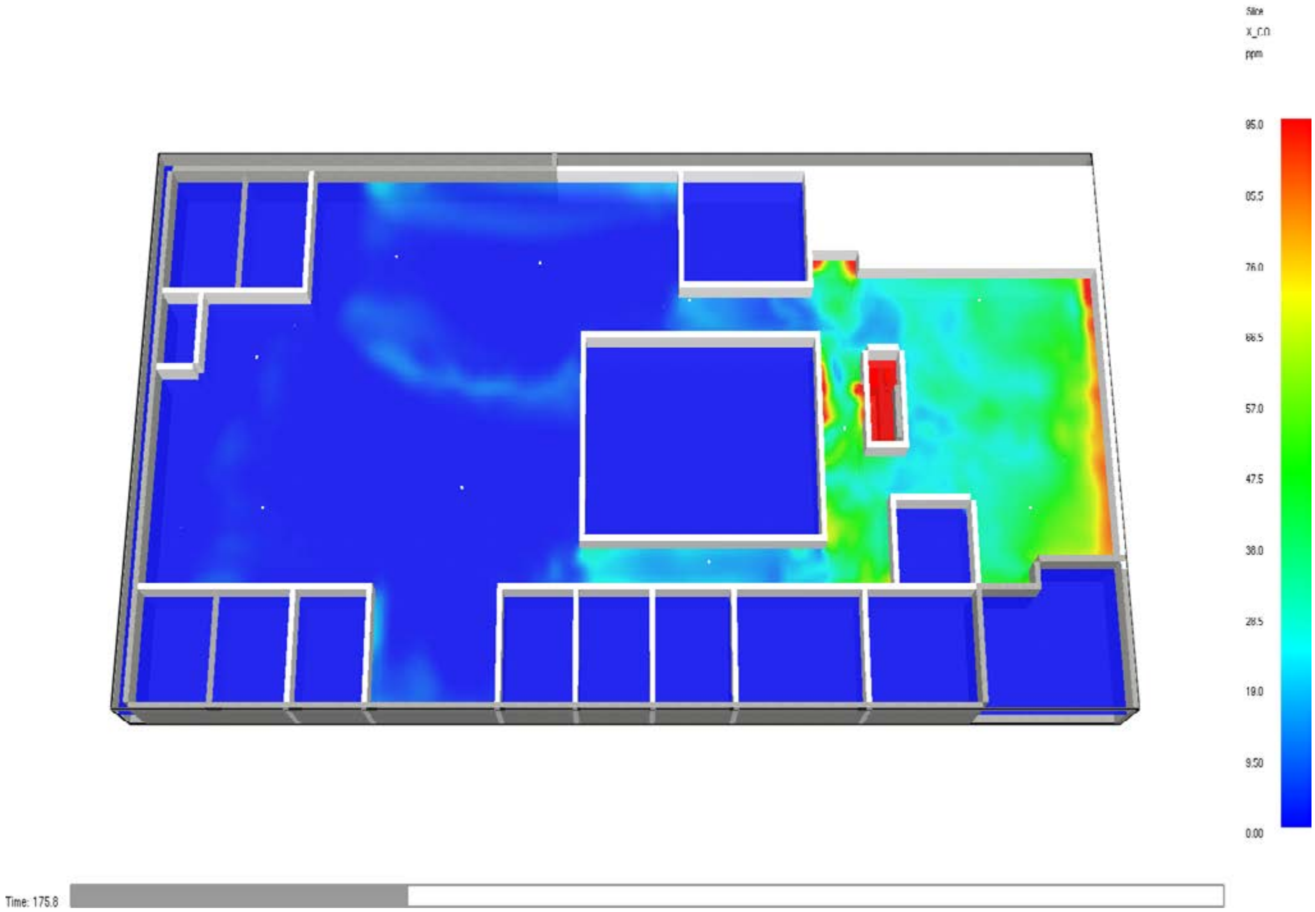


Figure 39 – Fire Scenario 1B: FDS CO @ 176s (RSET)

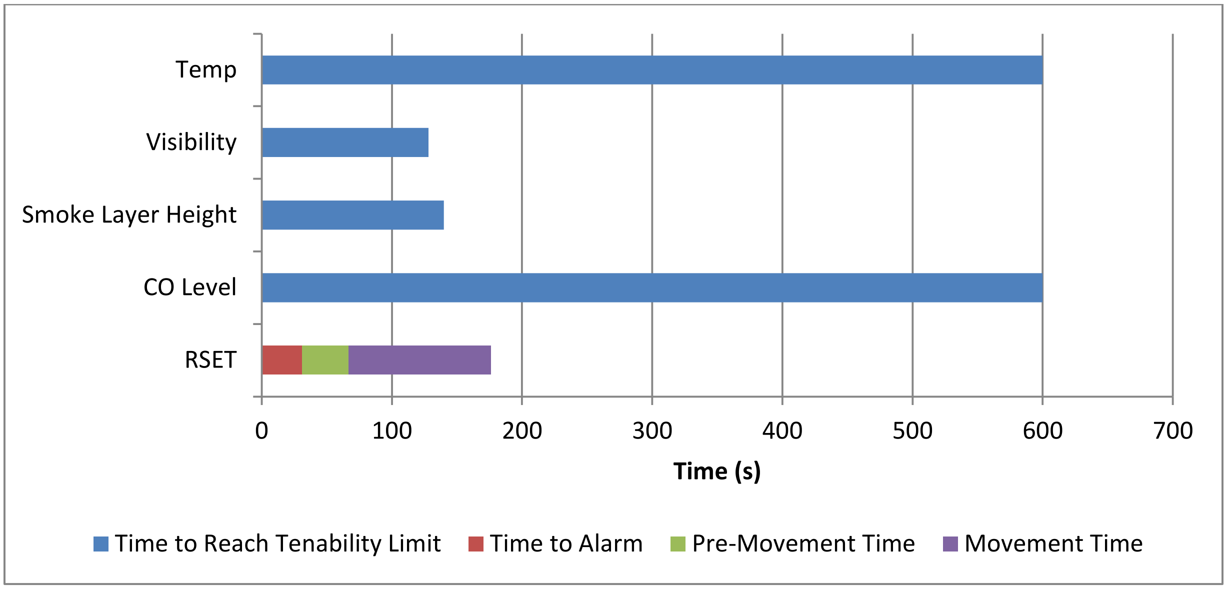


Figure 40 – Fire Scenario 1B: RSET vs. ASET Analysis

As shown in Figure 40 above, Scenario 1B fails the visibility and smoke layer height tenability requirements, however it passes the CO and temperature criterion so a percentage of the occupants could exit the building without being overcome with the effects of heat or smoke.

11.13.6. Summary

Two of the three criterion fail for Scenario 1A (no sprinklers) and 1B (sprinklers), however whether or not sprinklers are present, Scenario 1B proves that they do make a considerable difference with the reduction of the amount of carbon monoxide developed and temperature produced from the design fire.

12. Performance-Based Design Conclusion

Evacuation times were assessed based on the occupancy load factor of the floors. It was determined that the building optimal evacuation time is between 2-3 minutes if no exits are blocked. Based on the design fire scenarios, recommendations are as follows:

- Keep exits clear of obstructions and potential combustibles
- Limit amount of secondary combustibles (i.e., wood table) in kitchenette
- Replace suspect, old, or malfunctioning appliances
- Ensure a fire watch is implemented any time the sprinkler system is impaired

13. Conclusion

This report evaluated both the prescriptive and performance-based designs of the Production Facility. The prescriptive-based design applied to this building was covered and summarized in detail with an overview and review of the structural, egress, sprinkler, fire alarm, and building construction systems for the PF. The designs have been evaluated and discussed against the current adopted codes, standards, and DOE requirements.

The performance-based analysis of this report focused on evaluating how effective the performance-based requirements were in providing life safety for the occupants. It was found that the fire protection systems were not totally adequate for the building for both scenarios. Both scenarios failed to maintain the tenability conditions for the occupants during evacuation of the building. The performance-based analysis showed that visibility was the limiting condition for both scenarios.

There were deficiencies that were found that need to be addressed to meet current code requirements. The waterflow test is outdated and a new test will need to be conducted to ensure the water supply is still adequate for the facility requirements. Sprinkler system drawings and hydraulic calculations are incomplete or outdated and need to be reconstituted. Numerous items are located in the corridors and need to be removed to ensure adequate egress capacity and occupant egress safety.

The building construction meets the requirements for floor area and height limitations. The occupancy separations and fire-resistive wall construction was determined to be code compliant.

The egress system was determined to be code compliant. The number of exits for the first floor was determined to be more than adequate for the occupant load of the building. The common path of travel and travel distances were found to be code compliant.

The fire sprinkler design for the PF meets the requirements in NFPA 13 and DOE orders and standards. There are no major open findings or deficiencies related to the sprinkler design and installation.

The fire alarm system was designed and installed in accordance with NFPA 72 and DOE orders and standards. There are no major open findings, however there are areas in the building that have slightly deficient alarm decibel readings. A test of the audible devices will need to be made in order to adjust the sound levels of the installed devices.

The next section lists several recommendations for the fire protection systems of the PF. These recommendations will be evaluated by engineering personnel and service requests will be issued for contractors or SNL maintenance personnel to make necessary repairs.

14. Recommendations

Table 18 below, shows the recommendations of this report. The biggest issue is the placement of furniture and tripping hazards in the corridors of the facility. Once administrative controls are in place to mitigate these issues, then occupant egress time and occupant safety will be greatly improved.

Table 18. Recommendations

	Recommendation	Reason
1	Replace ordinary response sprinklers with quick response	Some of the Cleanrooms have ordinary response automatic sprinklers and due to high air velocities, quick response are required. There are some areas where this issue has already been resolved.
2	Perform Waterflow Test	The flow test used for analysis is out of date by 4-years. NFPA requires recent flow test data to be used. Due to scheduling issues, a new flow test has not yet been able to be performed.
3	Reconstitute sprinkler hydraulic calculations	Due to the unavailability of complete, updated sprinkler drawings and numerous sprinkler modifications over the life of the system, a sprinkler system evaluation should be done on each of the two systems serving the main building. This should include a complete set of drawings and hydraulic calculations that include all modifications that have been made to date.
4	Perform fire alarm audible test of entire bldg.	Based on audible dB readings within the last few years, some of the areas of the building are deficient in coverage.
5	Relocate items located in corridors	Recycling bins, news racks, tables, etc.

15. References

[1] U.S. Fire Administration; National Fire Data Center, "Fire in the United States 2003 - 2007," FEMA, 2009.

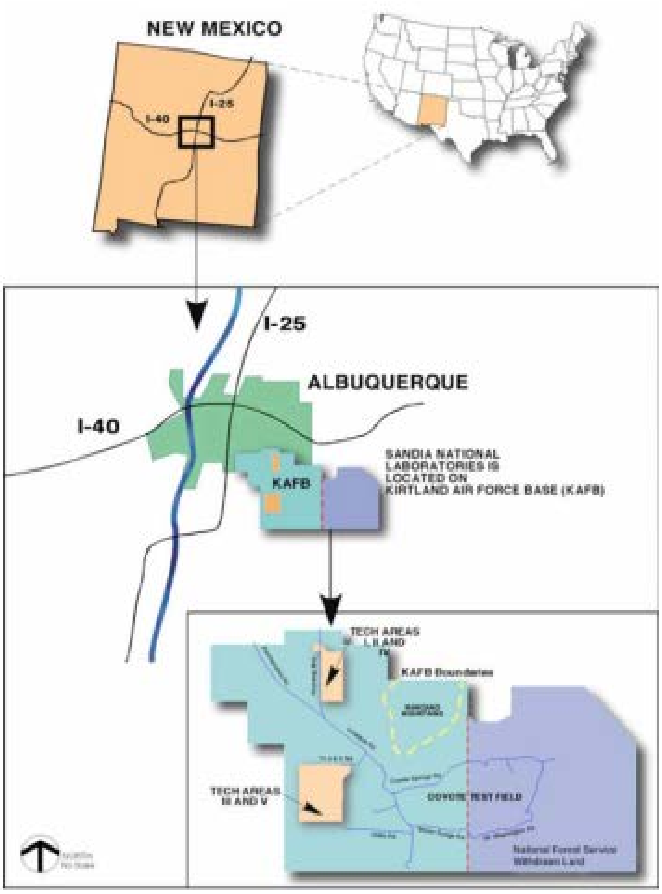
[2] SFPE Engineering Guide to performance-Based Fire Protection, 2nd Edition

[3] P. H. Thomas, "Testing Products and Materials for Their Contribution to Flashover in Rooms," in Fire and Materials, 1981, pp. 103-111.

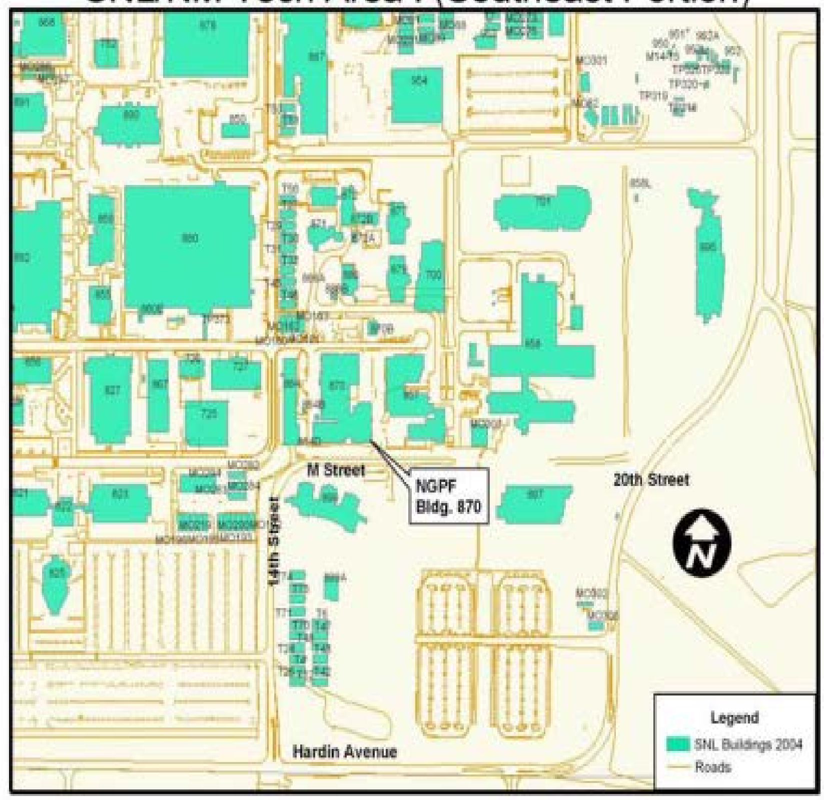
[4] University of Maryland, Burning Item Database

Sandia National Laboratories

Appendix A – Sandia National Labs Location Maps



SNL/NM Tech Area I (Southeast Portion)



Sandia National Laboratories

Appendix B – Occupant Loads/Floor

Appendix C – Rated Wall Locations

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Appendix D – Exit Locations

Appendix E – Egress Analysis Calculations

Appendix F – Exit Sign Locations

Appendix G – Fire Sprinkler Drawings

Appendix H – Sprinkler Device Cut-sheets

Appendix I – Fire Alarm Manufacturer Datasheets

Appendix J – Fire Alarm Shop Drawings

Appendix K – Battery and Voltage Drop Calculations

Appendix L – Structural Drawings

Appendix M – Preventive Maintenance Checklist

Appendix N – Computer-based Egress Model (Pathfinder)